DTIC FILE COPY

2

US Army Corps of Engineers

AD-A208 253

GEOTECHNICAL LABORATORY

TECHNICAL REPORT GL-89-6

THE INFLUENCE OF SOIL SURFACE CONDITIONS ON THE TRACTION OF WHEELED AND TRACKED MILITARY VEHICLES

by

Dennis W. Moore

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

April 1989
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

89 5 30 182

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): Technical Report GL-89-6

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION: USAEWES Geotechnical Laboratory

6b. OFFICE SYMBOL (If applicable): CEWESGM-T

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code): PO Box 631, Vicksburg, MS 39181-0631

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: US Army Corps of Engineers

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code): Washington, DC 20314-1000

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification): The Influence of Soil Surface Conditions on the Traction of Wheeled and Tracked Military Vehicles

12. PERSONAL AUTHOR(S): Moore, Dennis W.

13a. TYPE OF REPORT: Final report

13b. TIME COVERED: FROM Aug 88 TO Dec 88

14. DATE OF REPORT (Year, Month, Day): April 1989

15. PAGE COUNT: 144

16. SUPPLEMENTARY NOTATION: Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Military research (LC)
Motor-trucks, military (LC)
Vehicles, military--testing (LC)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The purpose of this study was to investigate a means of predicting the loss in vehicle traction associated with soil type and rainfall amounts. Firm soils were used which allowed only negligible vehicle sinkage. The soil types investigated were CH, CL, ML, SC, SM, and SP soils as classified by the Unified Soil Classification System . Incremental simulated rainfall was applied in 1/4-in. increments up to a maximum of 1 in. Eighty traction tests were used for this study with three state-of-the-art military vehicles. Results of this study indicate that the greatest loss in traction for most soil types is between the dry surface condition and 1/4 in. of rainfall. The more clay fraction in the soil, the more traction loss can be expected, with rainfall and the traction loss more appreciable for the wheeled vehicles than with the tracked vehicle.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE (Include Area Code)

22c. OFFICE SYMBOL

DD Form 1473, JUN 86 — *Previous editions are obsolete*

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

Personnel of the US Army Engineer Waterways Experiment Station (WES) conducted the study described herein as a portion of a larger research program during the period January 1986 through December 1987 in partial fulfullment of the requirements for the Degree of Master of Science in the Department of Civil Engineering at Mississippi State University.

The overall study was under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL), Mr. C. J. Nuttall, Chief (retired), Mobility Systems Division (MSD), GL, Mr. N. R. Murphy, Chief, MSD, and under the direct supervision of Mr. B. G. Schreiner, Chief, Mobility Investigations Group (MIG), MSD, GL. Mr. D. W. Moore (MIG), MSD, was responsible for this research and directed the field program described herein. Field test support was provided by Messrs. R. A. Jones, C. D. Cothren, D. M. Rogillio, D. E. Strong, A. C. Roberson, R. N. Tennant, L. Jackson, M. W. Gray, and Ms. T. L. Prickett, MIG. This report was prepared by Mr. Moore.

COL Dwayne G. Lee, EN, was the Commander and Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was the Technical Director.

ACKNOWLEDGEMENTS

The author is grateful to the US Army Corps of Engineers, for permission to use the information herein. Credit is also due to the author's supervisors at the US Army Engineer Waterways Experiment Station for their support of education and professional excellence among their subordinates. The author also extends his gratitude to his faculty advisor, Dr. Oswald Rendon-Herrero, his WES advisor, Dr. George Hammitt, and the remainder of his graduate committee.

Last, but not least, the author wishes to express his sincere appreciation to his wife, Ann, and daughters, Rachel, Lynsey, and Candace, for their love and support during this study and to whom this work is dedicated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER I

INTRODUCTION

Background and Literature Review

Traction problems with wheeled and tracked vehicles on weak or slippery-surfaced soils have been recognized by both the military and civilian industry for many years. Mobility problems have been encountered by the military at many locations throughout the world where intermittent rain showers may render a passable road impassable by creating wet slippery surface conditions. Also, when a vehicle must be driven off-road, where no previously traveled road exists, intermittent showers may cause severe mobility problems. These problems are difficult to describe since they involve a complex interplay of several variables with soil moisture content and soil type playing the larger role. The measurement of the loss in surface shear strength with increased soil moisture is difficult to measure in the field environment. However, by varying the moisture in a field environment and measuring the resulting effects on the performance of a vehicle operating on the resultant soil surfaces, the effect of the strength loss may be evaluated. (The definition of terms used in this study are given in Appendix A.)

A literature review was conducted to determine if any study had been done in this area before. Previously, two studies were conducted, one with a single pneumatic-tired wheel on one soil type in a laboratory test, and the other was a field test using a 4x4 vehicle on four soil types.

The study herein was conducted at two locations near Vicksburg, Mississippi, and at one location on the Fort Chaffee Military Reservation near Fort Smith, Arkansas. The test locations near Vicksburg were located on the west side of the Mississippi River near Thomastown, Louisiana, and some 7 miles south of Vicksburg near LeTourneau, Mississippi, as shown in Figure 1. The test location at Fort Chaffee was located east of the main post as shown in Figure 2.

The area along the Mississippi River near Thomastown, known locally as Duckport, was selected because of the CH, CL and SP soil types, according to the USCS, that exist. The CH soil was located on a trail that was devoid of vegetation. The CL soil was located in a nearby grassy field which was scraped clean by a grader before the conduct of the tests. The SP soil was located along the banks of the Mississippi River.

The ML soil was located at the LeTourneau test site where a level, bare area of compacted silty trail was used.

The SC and SM soils were located on the Fort Chaffee Military Reservation. Both of these test areas were initially covered with 18-24 inches of high weeds and grasses, but were also cleared by a motor grader.

The gradation curves for all of these soils are shown in Figures 3-8.

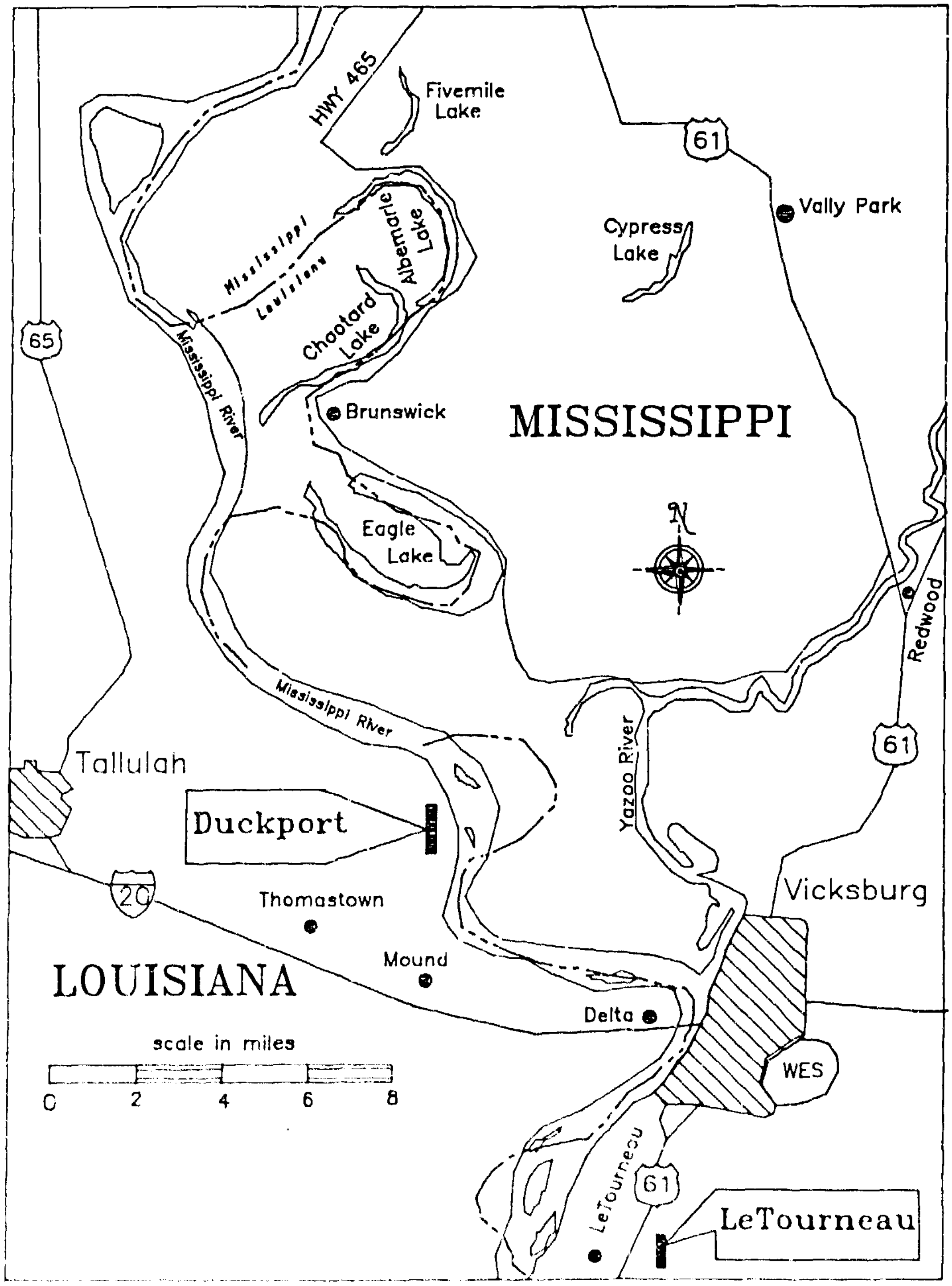


Figure 1. Vicksburg Local Test Sites

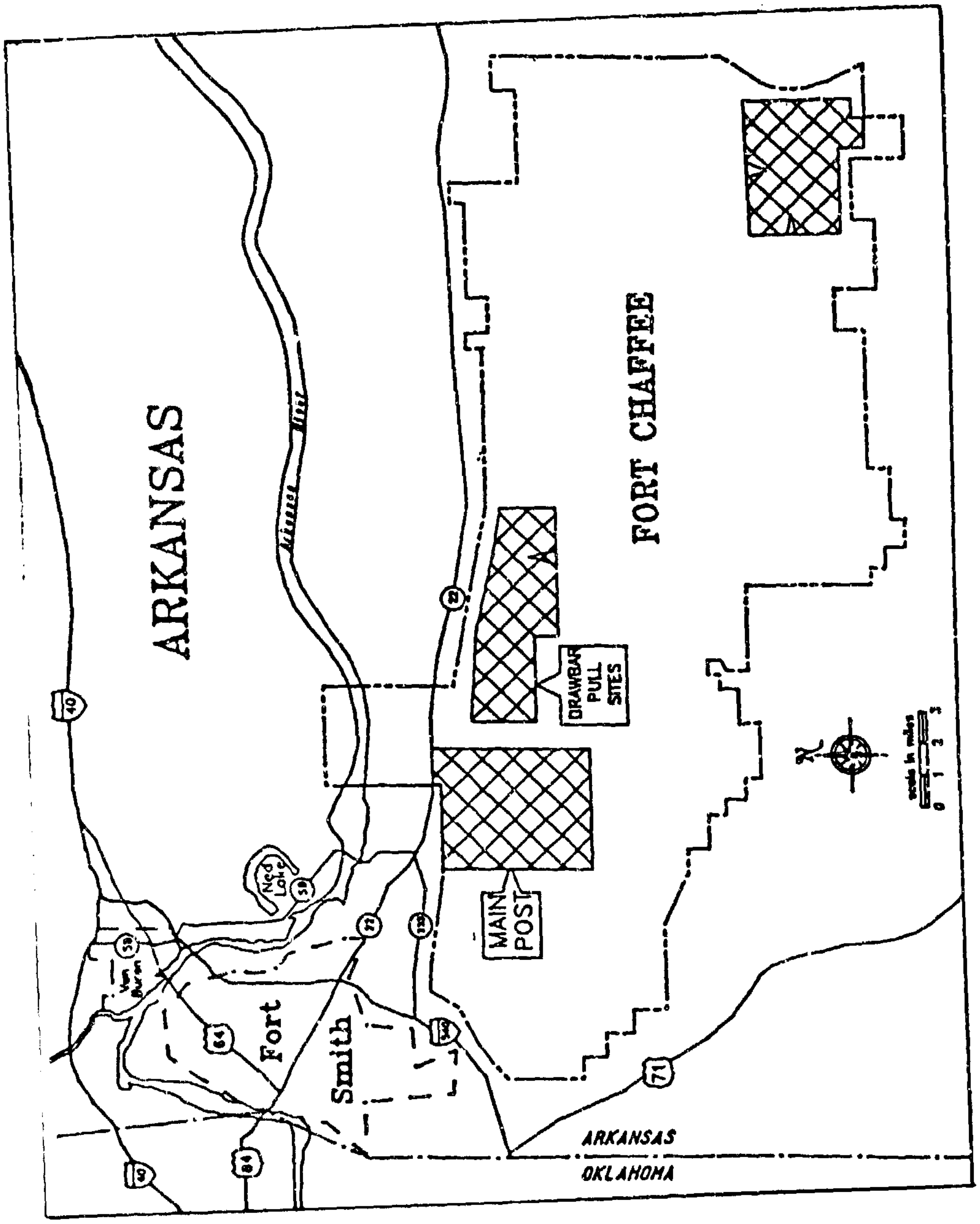


Figure 2. Fort Chaffee Test Sites

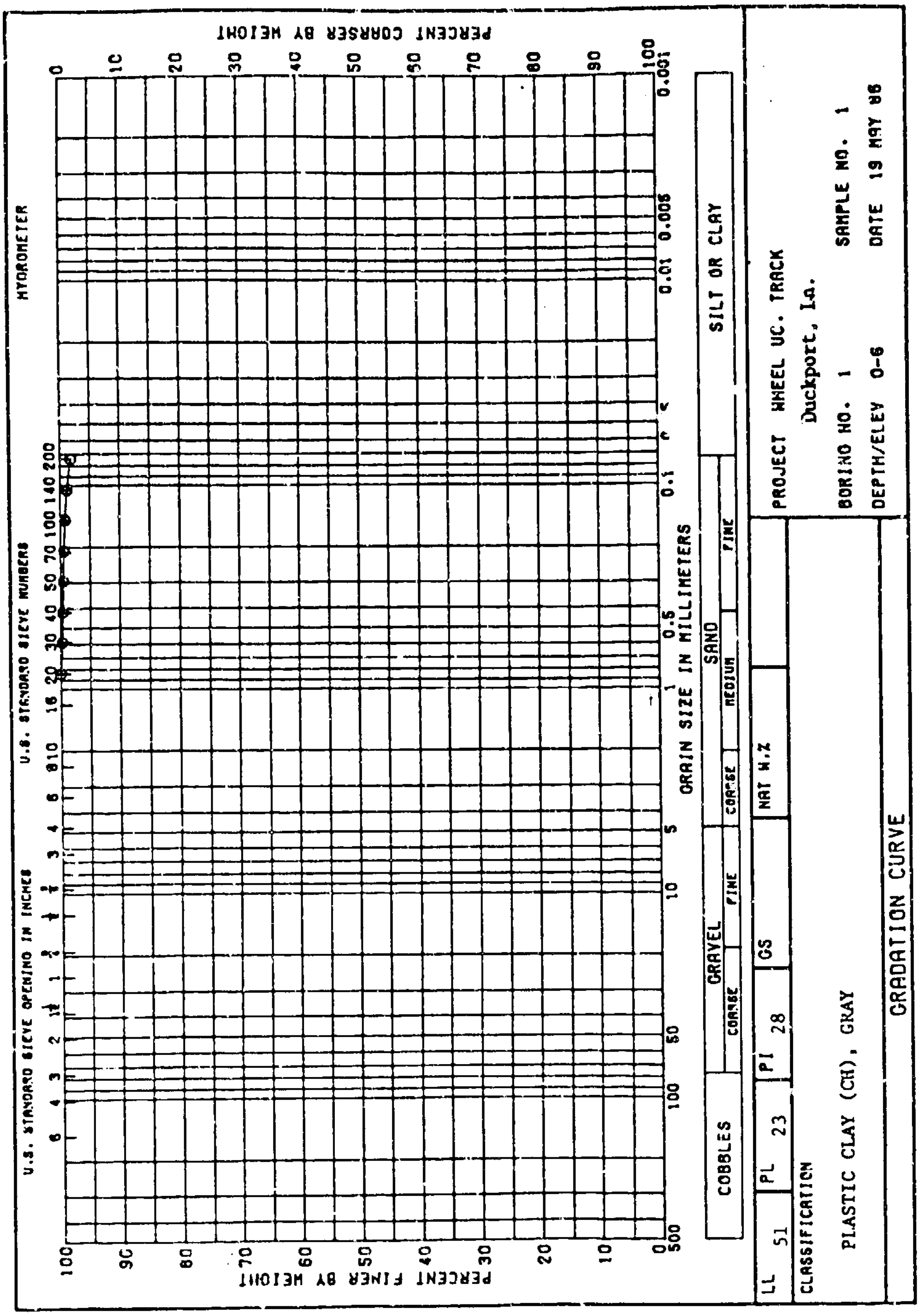


Figure 3. Soil Classification, CH Soil

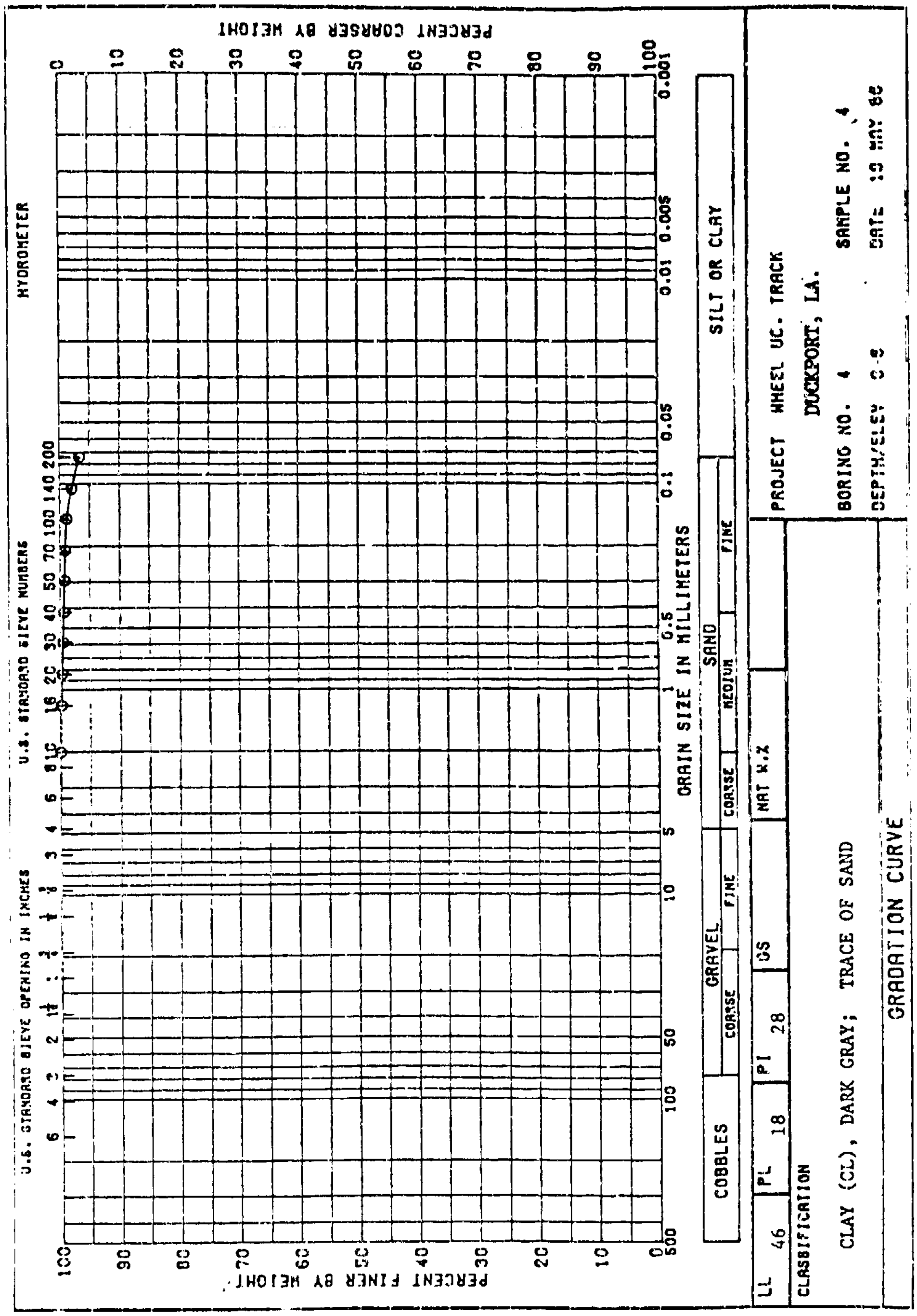


Figure 4. Soil Classification, CL Soil

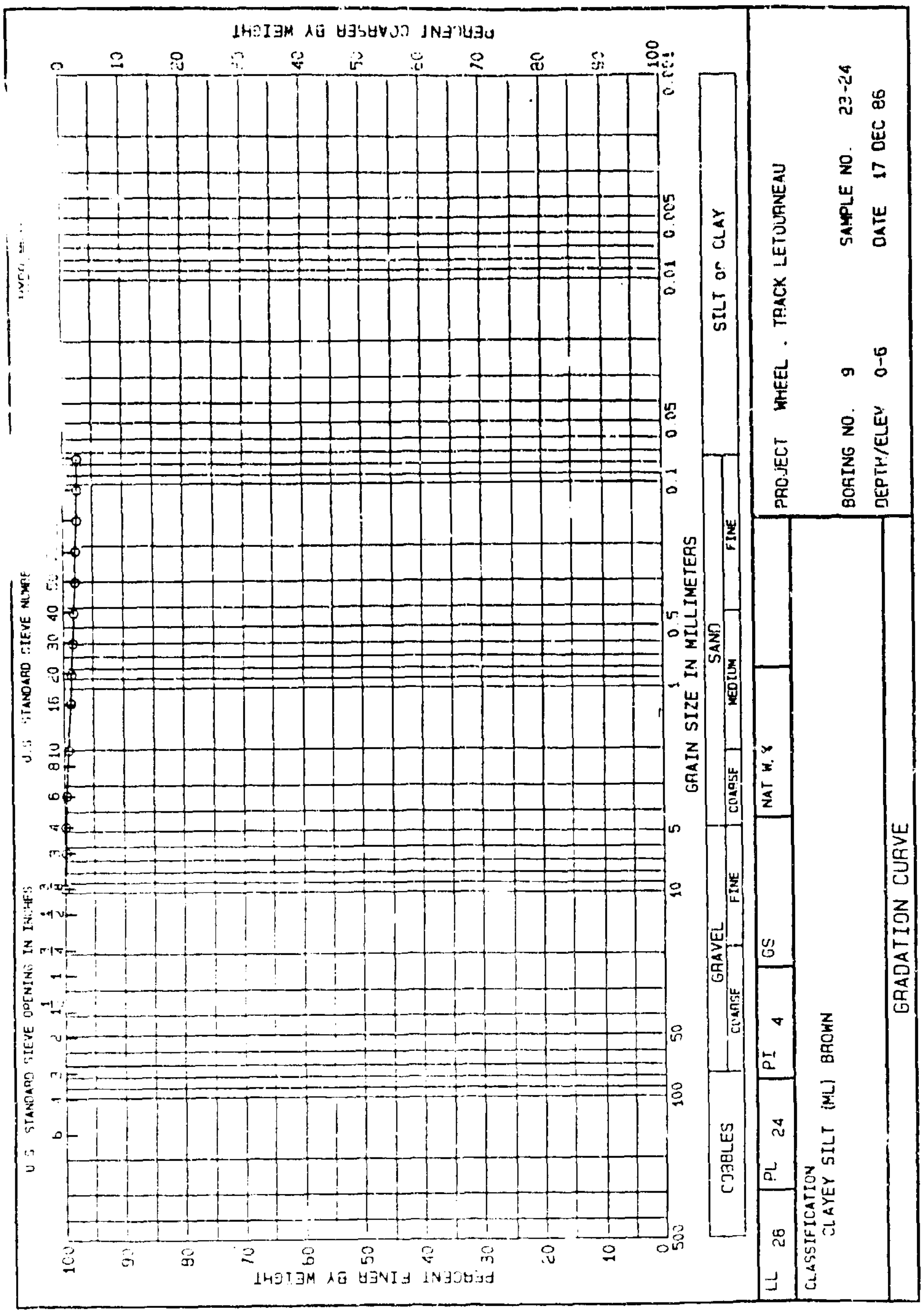


Figure 5. Soil Classification, ML Soil

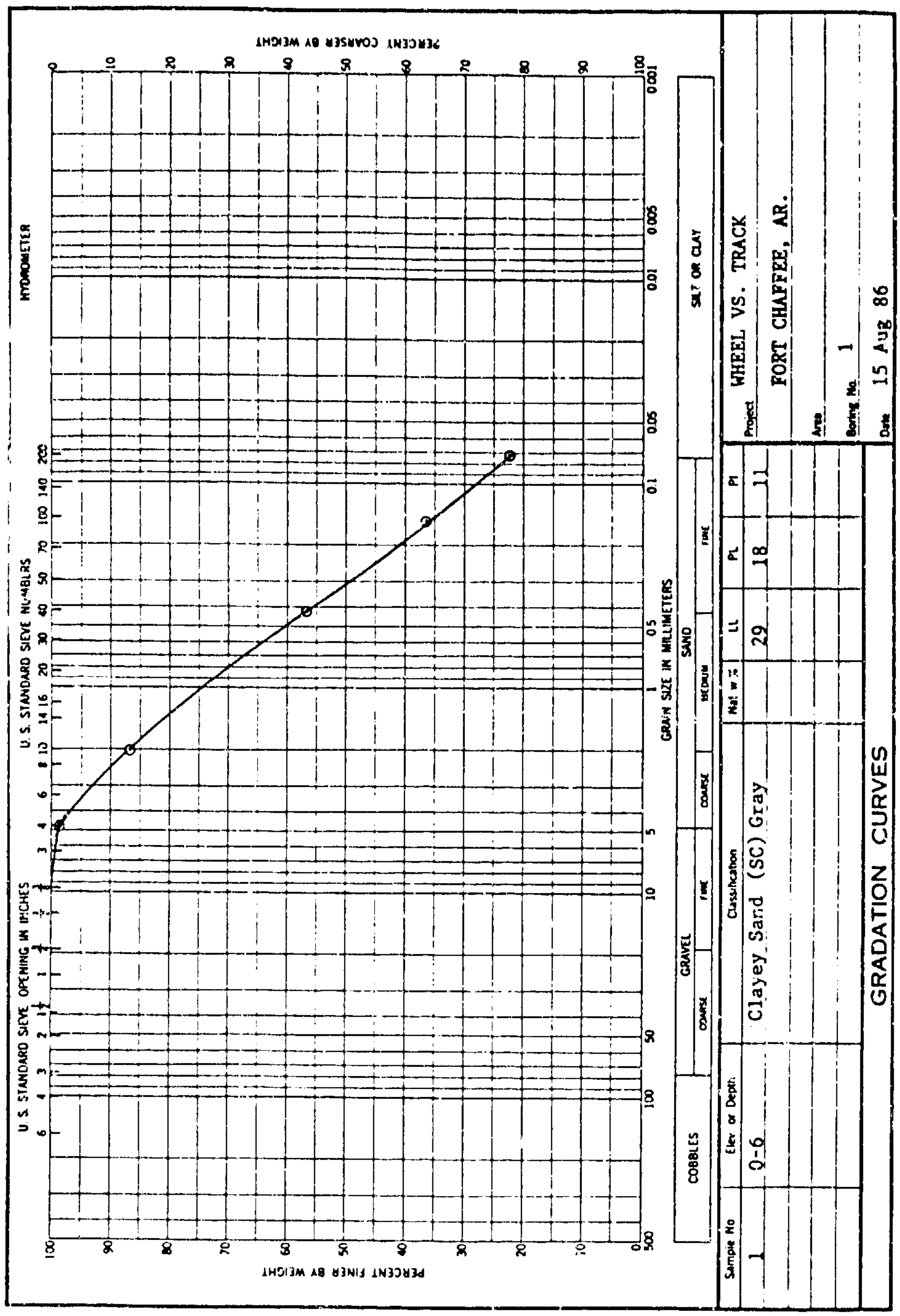


Figure 6. Soil Classification, SC Soil

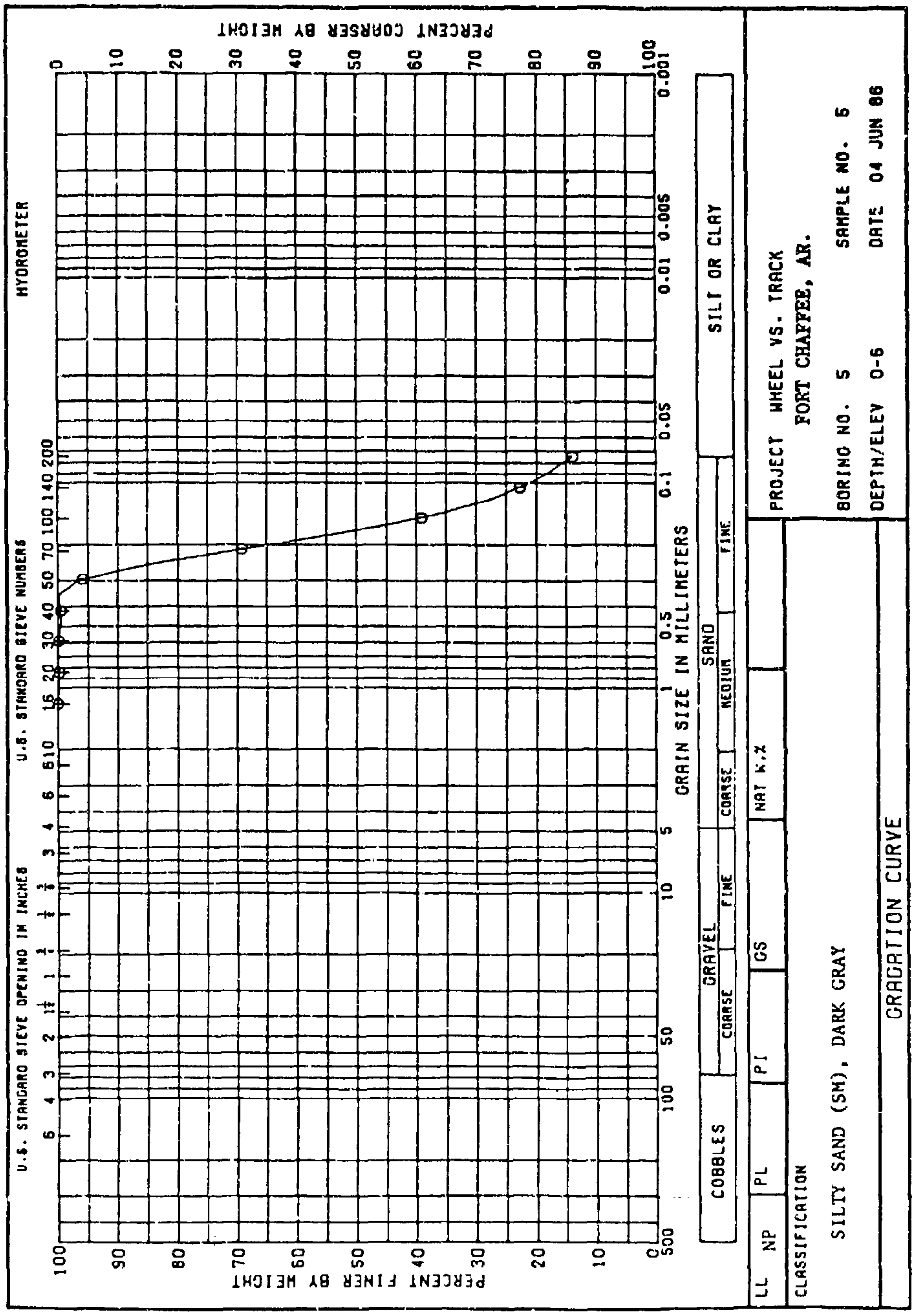


Figure 7. Soil Classification, SM Soil

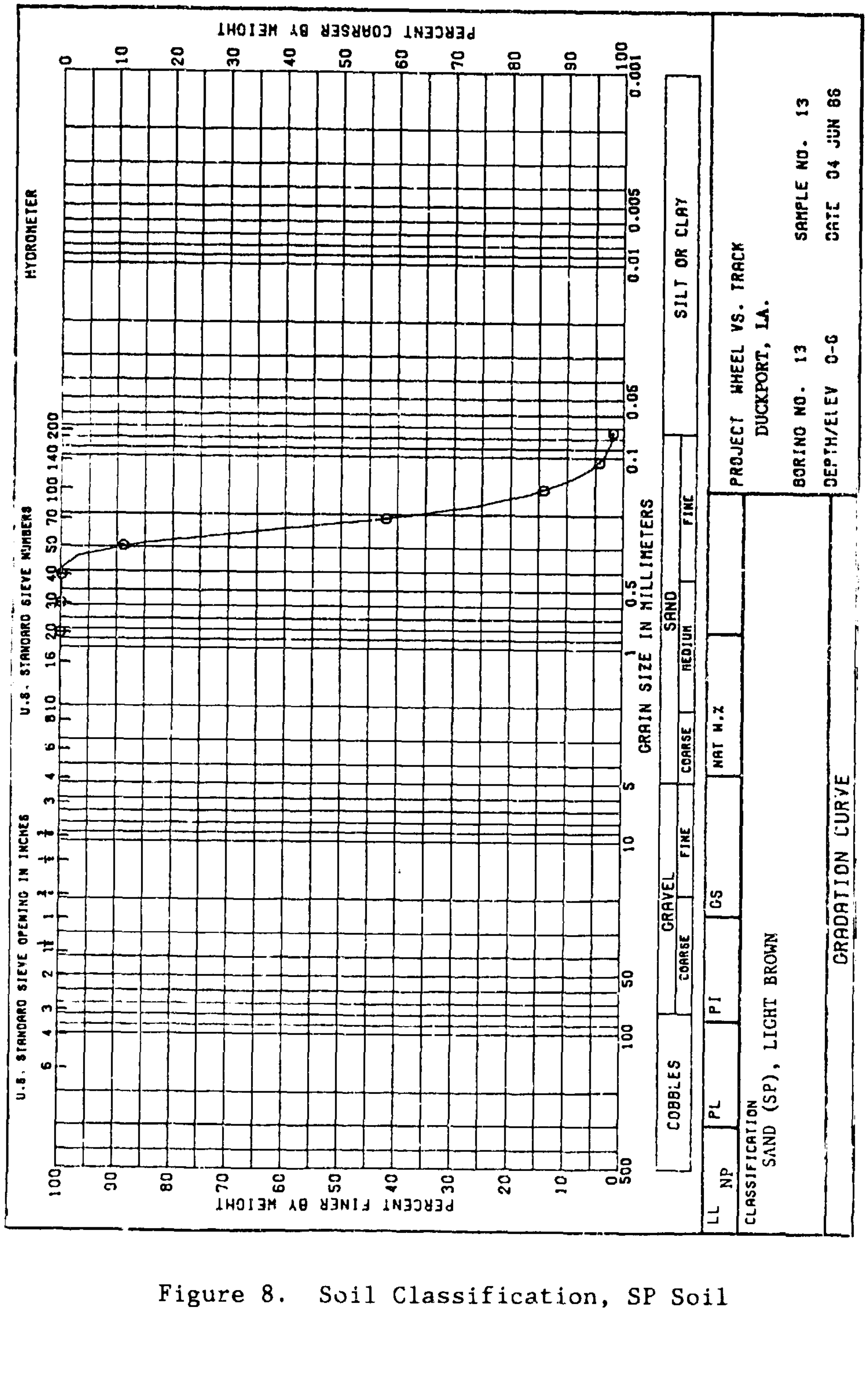


Figure 8. Soil Classification, SP Soil

Purpose

The purpose of this study was to investigate a means of determining the loss of traction associated with soil type and rainfall amounts. The firm soils allowed only negligible vehicle sinkage, insuring results in which traction is not governed by mass soil properties of the base layer, but by moisture effects on the surface of the soil. This study does not consider rainfall duration but instantaneous results after an intermittent rain shower.

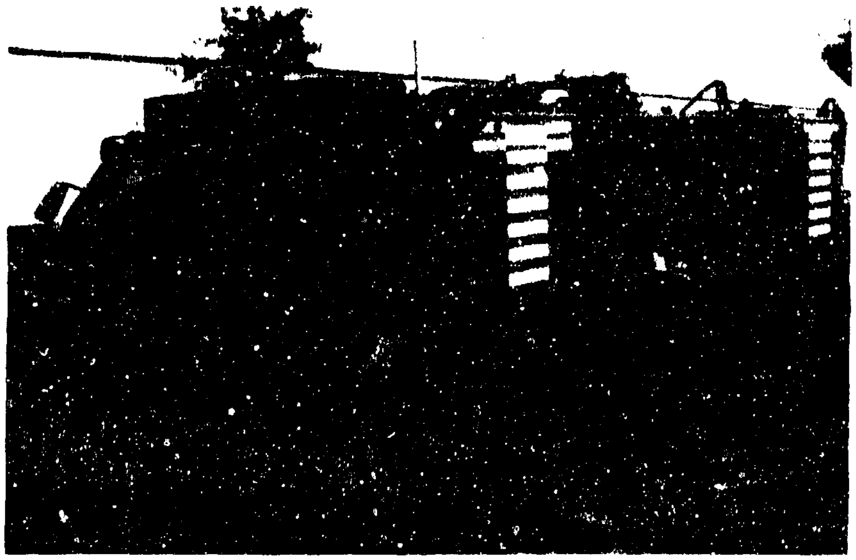
Scope

Eighty traction tests were used for this study with three state-of-the art military vehicles on the aforementioned soil types over a range of simulated rainfall conditions. Correlations of loss of traction in terms of drawbar pull or drawbar pull coefficients and rainfall amounts were developed.

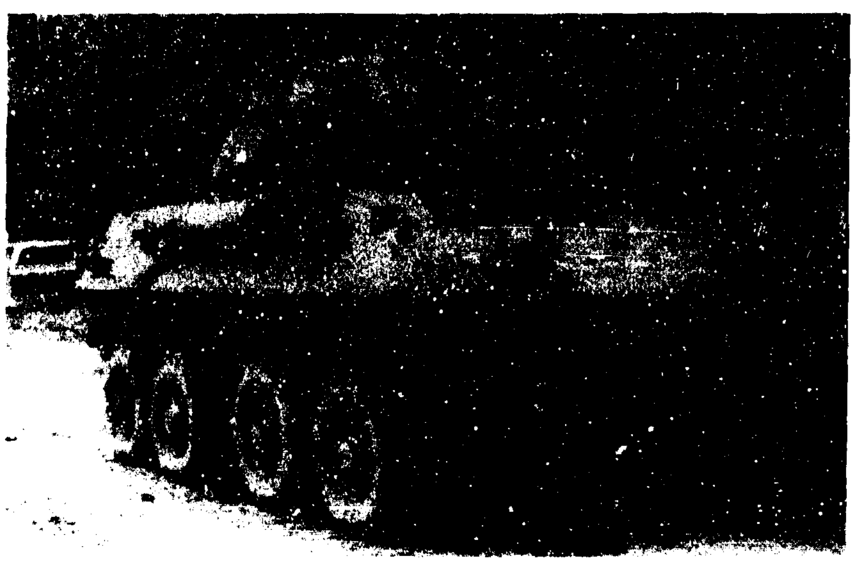
The test vehicles used were an M113A1 Armored Personnel Carrier (tracked vehicle), an LAV25 Light Armored Vehicle (8X8 wheeled vehicle), and a M977 Heavy Expanded Mobility Tactical Truck (HEMTT) (8X8 wheeled vehicle). Vehicle characteristics and pictures of the vehicles are represented in the following tabulation and Figure 9, respectively.

Vehicle Number	Vehicle Name	Measured Vehicle Weight Pounds	Tire or Track Nomenclature	Tire Inflation Pressure Pounds/ $inch^2$	Nominal Ground Contact Pressure Pounds/ $inch^2$	Horse Power/ ton
1	M113A1	23,400	Padded track	--	7.43	18.12
2	LAV25	26,895	Michelin 11.00R16	42	37.28	20.45
3	HEMTT	60,375	Michelin 16.00R20	35/40	32.79	14.31

All tests were conducted in low range all-wheel-drive. Complete oscillograms of each test were recorded with an Astromed Dash 4 oscillograph using a Baldwin 50,000-pound load cell attached between the test and load vehicle by steel cable. The tests were initially conducted on the in situ soil at natural surface moisture for baseline data. Next, the test lane was sprayed with water to simulate rainfall. The artificial rainfall was applied in 1/4-inch increments and the tests repeated. Tests were continued up to a maximum of 1 inch or the point at which the vehicle performance did not substantially change from one wetting to the next. Pertinent soil strength data were collected for each test using the US Army Engineer Waterways Experiment Station (WES) hand-operated cone penetrometer and soil moistures were taken at various depths to insure that the rainfall did not affect soils at depths. Adequate soil was also collected for soil classification. For consistency, all tests were conducted 5 minutes after the completion of each incremental wetting.



a. M113A1 Armored Personnel Carrier



b. LAV25 Light Armored Vehicle

Figure 9. Test Vehicles (Continued)

c. Heavy Expanded Mobility Tactical Truck (HEMTT)

Figure 9. (Concluded)

CHAPTER II

EXPERIMENTAL PROCEDURE

Introduction to Experiment

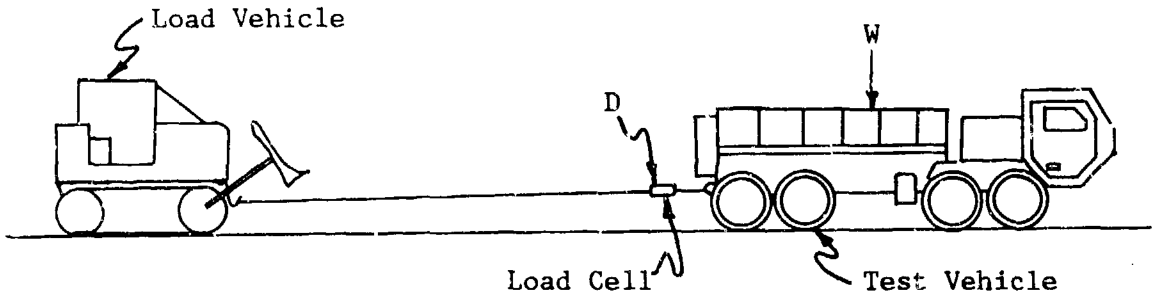
This experiment was conducted to determine if a reasonably accurate prediction can be made of the traction loss on, or a reduction in surface shear strength of, various soil types by the addition of surface water. The experiment was designed after several trial and error tests were conducted to determine the best method for the conduct of these tests. Once the method was established, the writer personally directed all of the tests in this study and supervised the collection and reduction of the field data.

Test Procedures

The off-road performance of a vehicle is dependent, to a large extent, on the net traction that develops between the ground surface and the running gear. Even though the soil strength may be adequate to support the vehicle, dramatic reductions in performance can occur with traction loss in sand or wet, fine-grained soils. The total traction of a vehicle on a given soil condition is the sum of the drawbar pull developed by the vehicle on the soil and the soil resistance that is overcome by the traction elements in developing useful work or making forward progress. Because the total traction is difficult to measure in itself, the two additive values of drawbar pull and towed motion resistance are usually measured singly and added to determine the total traction. The drawbar pull, however, varies with wheel slip which must be computed for each measured value of instantaneous drawbar pull.

In each soil test series with each configuration, an unsurfaced section of trail or adjacent soil was initially bladed smooth when dry, to remove any vegetation or surface irregularities. The test vehicle was positioned outside but in line with a test lane with a D6 or D7 bulldozer a short distance behind. A 50,000-pound load cell and 50 feet of 5/8-inch steel cable were attached between the rear pintle hook of the test vehicle and the towing hook on the undercarriage of the dozer. A string playout system, composed of a wire cable wound on a large reel attached to a calibrated instrumented playout unit, was mounted on the side of the test vehicle to provide an accurate measure of true ground distance. A calibrated magnetic reed switch was attached to the drive shaft to provide a means of computing average vehicle wheel or track slip during testing. Prior to each test a sufficient number of cone index measurements were made to determine the average soil strength in the test lane. Soil samples for determination of moisture content were collected prior to each test. The soil strength and moisture data were taken to compare different tests to insure that similar conditions existed. A schematic of the drawbar pull test is shown below.

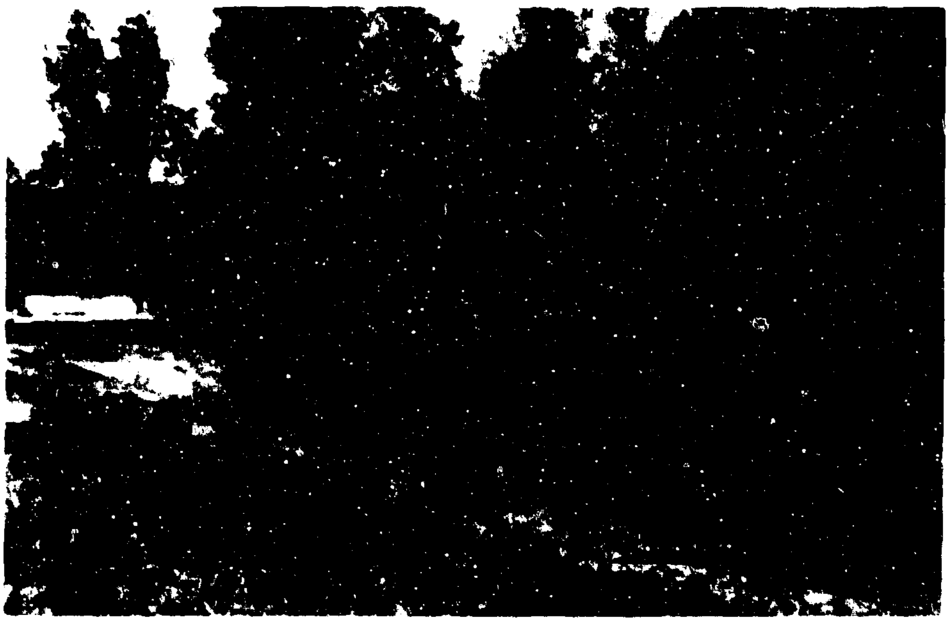
D/W = Drawbar Pull Coefficient (Drawbar pull/vehicle weight)



During each drawbar pull test, the test vehicle was operated in its lowest gear at optimum engine rpm (speed of 2 to 5 mph) and proceeded into the test lane with the dozer following in a manner such that the cable between the two was in a slack, unloaded condition. The dozer operator gradually applied braking force which gradually increased the loading on the test vehicle in stages up to a "high load-high slip" condition and finally a "100 percent slip" point, wherein the test vehicle made no significant forward movement. Photographs of drawbar pull tests are shown in Figure 10. The actual measured vehicle pull-slip curve was calculated from the onboard magnetic tape test record by measuring various values of drawbar pull with the corresponding measure of vehicle and ground speed. The vehicle slip in percent is equal to:

$$\text{Slip} = \left[1 - \frac{\text{Distance traveled by string playout, feet}}{\text{Apparent distance traveled by vehicle running gear, feet}}\right] \times 100$$

a. LeTourneau Test Site, HEMTT, ML Soil



b. D7 Dozer Loading HEMTT

Figure 10. Drawbar Pull Tests

Sufficient measurements were made in this manner to develop a complete drawbar pull-slip curve for the test vehicle in each soil condition at each test location.

The procedure used for measuring the rolling or motion resistance in each test area was to tow the vehicle backward from the 100 percent slip point in the drawbar test in neutral gear with engine idling at a speed of approximately 2 mph. After each traction test, the vehicle was steered into an undisturbed area adjacent to each drawbar lane and into a position straddling the ruts of the traction test. The dozer then towed the test vehicle backward through the lane with the steel cable and connected load cell. The test vehicle was out of gear (neutral) with engine running and the towing speed was maintained at or near 2 mph for a sufficient distance to permit the motion resistance to stabilize and be recorded on magnetic or paper tape for record.

After the drawbar pull and motion resistance tests on dry soil, an area of dry trail 300 × 12 feet was uniformly sprayed with water from a water truck in applications sufficient to produce a rainfall equivalent of 1/4 inch. After 5 minutes of elapsed time to allow for soaking or runoff, drawbar pull-slip and towed motion resistance tests were conducted as previously described. After these tests, the area was again sprayed with the same quantity of water (1/4 inch of equivalent rainfall) to produce an equivalent total rainfall of 1/2 inch. Again, 5 minutes of time elapsed before drawbar pull and motion resistance tests were conducted. Testing continued in this repetitive manner until drawbar pull values leveled off or until 1 inch of equivalent rainfall had been sprayed onto the test lane. Each time a test was conducted the vehicle was positioned in a different location in the test lane to insure that the tests were conducted on undisturbed soil. After each wetting, cone index measurements were made along the test lane and moisture content samples from the surface, 0-3-inch, and 0-6-inch depths were taken before and after each test.

Drawbar Pull-Slip Tests

Sufficient drawbar pull values (pounds) were collected from the oscillogram for each test conducted, along with the corresponding value of vehicle slip, and used to develop a drawbar pull-slip curve or a drawbar pull coefficient-slip curve. The drawbar pull coefficient (drawbar pull/vehicle weight) is used in order to make comparisons for vehicles of different vehicle weights. Table 3 shows the drawbar pull test results for each test. On each oscillogram, as shown in Figure 11, segments representing constant pulls of short duration are measured relative to a calibrated scale determined by the oscillograph operator and properly annotated at the beginning of each oscillogram. Vehicle slip is determined by counting the number of string play-out marks (one mark equals 6 inches of vehicle travel) to obtain true ground distance and the distance traveled by the wheels or tracks relative to a particular segment on the load curve. The distance traveled by the wheels or tracks, which may vary for each wheel or track, is calibrated to revolutions of the vehicle drive shaft for the wheeled vehicles, or the revolutions of the track sprocket for the tracked vehicle, to the average wheel or track distance traveled for the entire

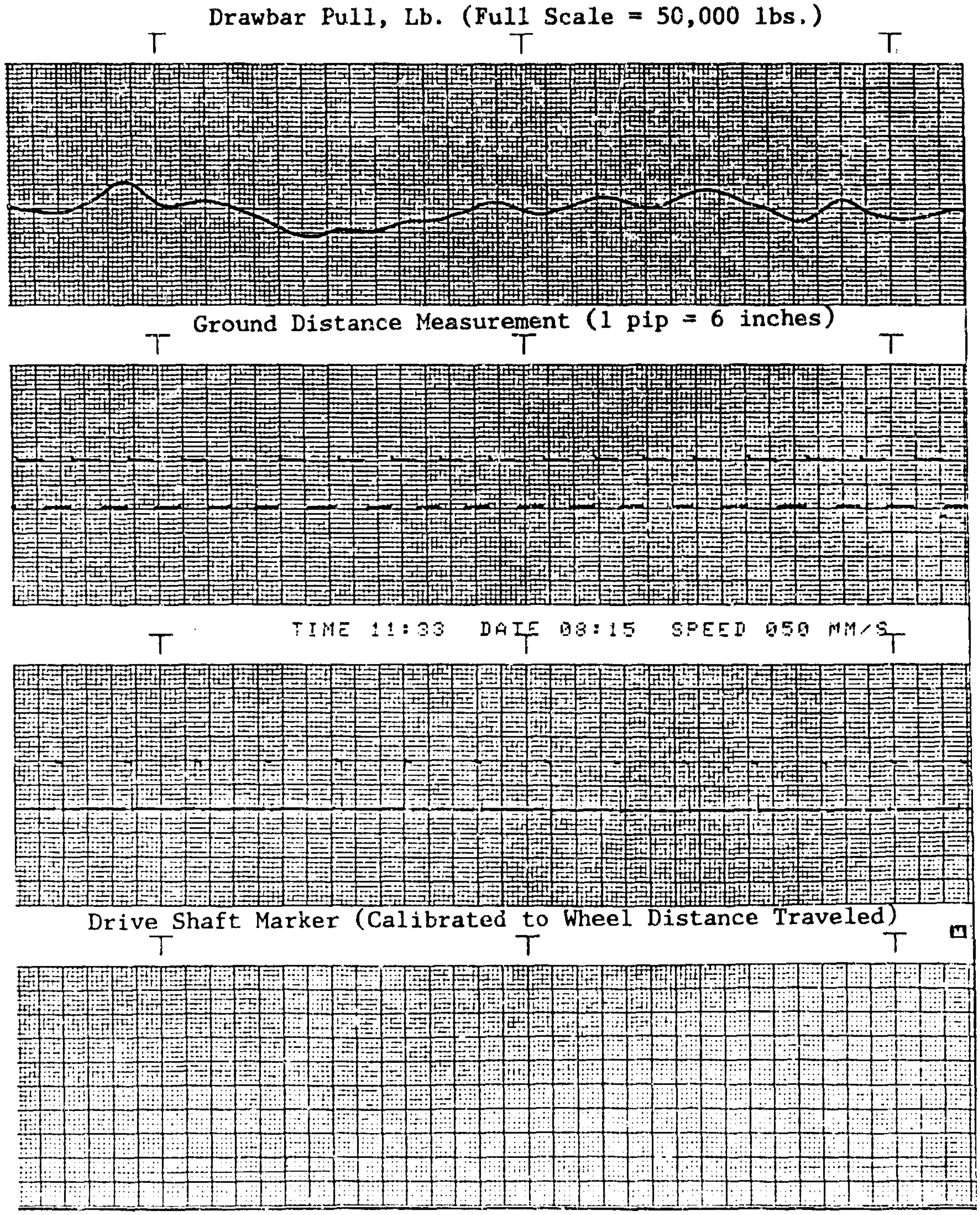


Figure 11. Oscillograph Data

vehicle. The wheel or track distance traveled is divided into ground distance traveled by the vehicle, to determine the percentage of vehicle slip relative to the measured value of drawbar pull at each segment. The values of drawbar pull are then divided by the vehicle weight to determine the drawbar pull coefficient for each segment. The drawbar pull coefficients and the corresponding slip values are then plotted relative to each other. These plots are shown in Plates 19-48.

CHAPTER III

RESULTS

Computations

Drawbar Pull Coefficient-Slip Curve Fitting

In the past at WES, visual curves of best fit were drawn through the data points and the drawbar pull coefficients for a particular percent slip were then graphically determined. However, past mobility studies at WES indicated that the two-constant hyperbolic equation well represented stress-strain responses from both cohesive and frictional soils in laboratory specimens and that typical pressure-sinkage relations from plate penetration tests also were reasonably approximated by the equation.

The drawbar pull coefficient (D/W)-slip data are shown in the composite plot (Figure 12) represented by triangular symbols for the LAV25 on the CH soil in a dry surface condition. It can be seen that if a visual curve were drawn through these data, it would have the general appearance of a rectangular hyperbola. This suggests a possible relationship between the experimental D/W-slip curve and the hyperbola. This relationship is also demonstrated in Figure 12, (slip = x, D/W = y), by plotting x/y versus x. From this plot, shown by the square figures, the data lie near a straight line. The near linear arrangement of the plotted points indicates that the D/W-slip curve closely follows the path of a rectangular hyperbola and can be expressed mathematically as a rational equation in terms of D/W and

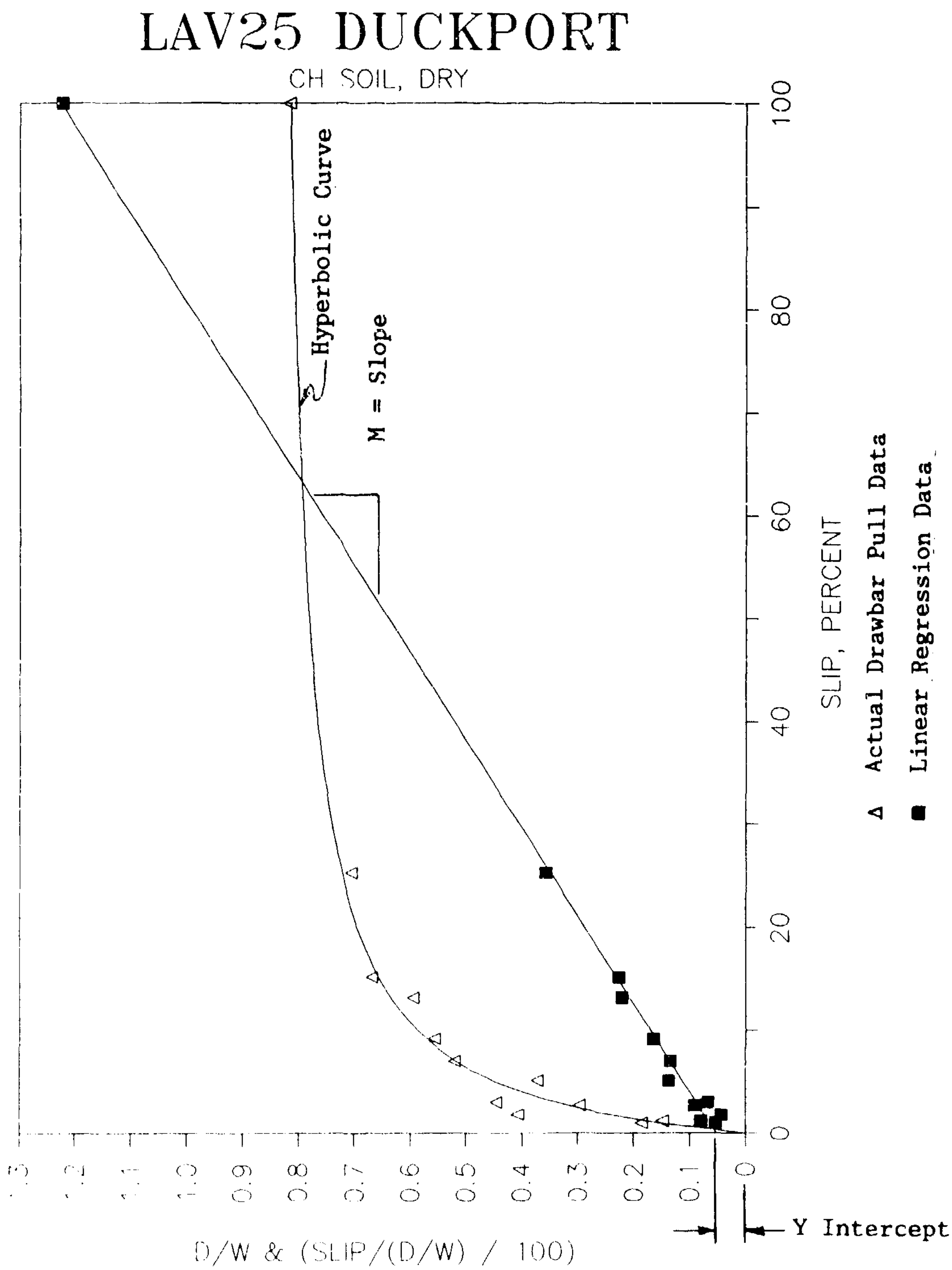


Figure 12. Drawbar Pull-Slip Curve Fitting

slip. This relationship is expressed by the hyperbolic equation in the form:

$$y = \frac{x}{mx + b}$$

This equation was solved, using a personal computer (PC), for the linear regression values of slope (m) and y-intercept (b) for the corresponding increments of slip (x), to yield corresponding values of D/W (y) as a means of best fit to the measured field data. The linear regression line (Figure 12) was computed using values of x (0-100) and corresponding values of x/y . The final hyperbolic curve, also shown in Figure 12 was also plotted using x (0-100) and corresponding values of y . The regression output from the PC is shown below

Constant	0.05293775
Std Err of Y Est	0.01610381
R Squared	0.99775892
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.01173503
Std Err of Coef.	0.00017587

The results of the regression show that the hyperbola fits the data very well.

All of the D/W-slip data for each drawbar pull test were reduced in this manner and are plotted as a family of curves relative to rainfall-vehicle-soil type and are shown in Plates 1-18.

Drawbar Pull Coefficients at 20 Percent Vehicle Slip

The family of curves (based on vehicle-soil conditions) of drawbar pull coefficient-slip were next used to obtain the drawbar pull coefficient at 20 percent vehicle slip. Past trafficability studies at WES have shown that the optimum work output of a vehicle occurs at or near 20 percent vehicle slip. At this point, the slip is relatively low, while the drawbar pull coefficient is 80 to 90 percent of the maximum pull, which for most soils usually occurs at 100 percent slip. However, at 100 percent slip the work output of the vehicle is zero, because the vehicle is not making any forward progress (vehicle is spinning in place). The values of drawbar pull coefficient at 20 percent vehicle slip, obtained from the hyperbolic-generated data, are tabulated in Table 1. These data, for 20 percent slip, were then used with simulated rainfall values for each soil type to produce plots of drawbar pull coefficient at 20 percent slip (D/W_{20}) versus rainfall (inches) and are shown in Plates 1-18. These curves, when grouped together by vehicles, produced relationships that will be discussed in the following paragraphs.

Analysis

Soil Type-Rainfall Relationships

The average D/W_{20} values for all vehicles on each soil type were plotted against the increments of simulated rainfall to show the soil type-rainfall relationships. From this plot (Figure 13) it can be seen, in general, that the more clay fraction in the soil, the more

COMPOSITE OF SOIL TYPES

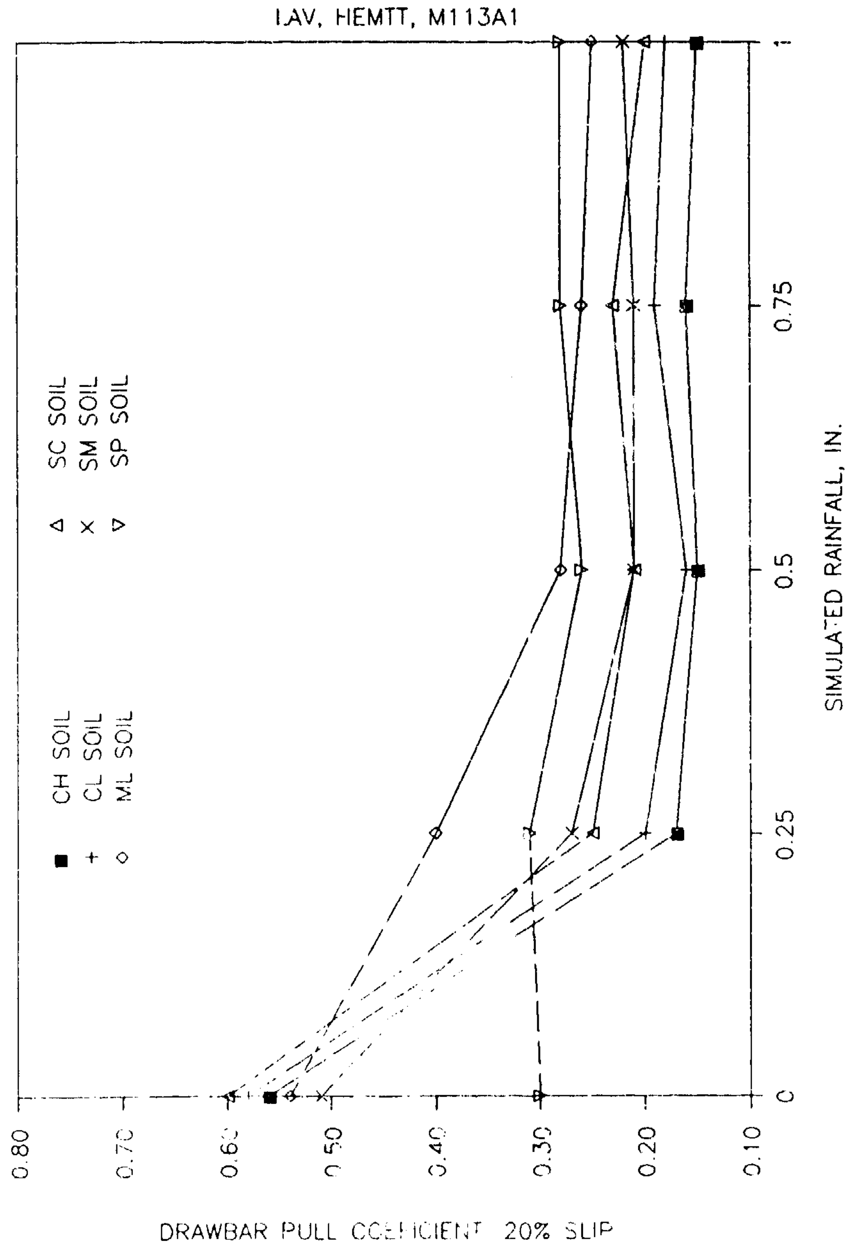


Figure 13. Soil Type - Rainfall Relationships

slippery (plastic) when wet the soil becomes and the smaller the resulting tractive coefficient or D/W_{20}. For 1/4 inch of simulated rainfall, the soils in order of the lowest D/W_{20} value to the highest, are CH, CL, SC, SM, SP, and ML. This order shows that as the clay content in the soil decreases, the traction of the vehicles increases. The same is true for the 1/2-, 3/4-, and 1-inch simulated rainfall amounts even though the plot shows some slight variations from the 1/4-inch order for the soils. Also, the CH and CL soils had similar results and at times the CL soil would have a lower D/W_{20} value for some of the wettings. This may be due to the properties of the soils. The CH soil's liquid limit (LL) was 51 percent, while the CL soil had a LL of 47 percent and they both had a plasticity index of 28. Therefore, both soils were very close to the dividing line between a CH and CL soil which is a LL of 50 percent.

Additional rainfall does not appear to significantly influence traction losses beyond the 1/4-inch amount. The plot (Figure 14) shows that the D/W_{20} tends to level out beyond 1/4 inch, except for the ML soil which did not level out until 1/2 inch of rainfall. This could possibly be due to the low plasticity of the ML soil which may require more water before it becomes slippery. Also, note that on the plot the lines connecting the dry condition and 1/4 inch of rainfall for all soils types are dashed. This was done to show that the traction loss between the dry and 1/4-inch rainfall may not be linear. No tests were conducted with rainfall values of less than 1/4 inch. The D/W_{20} for the SP soil has a tendency to be level from the dry surface through 1 inch of simulated rainfall. This is to be expected however, because the poorly graded sand does not become slippery when wetted. The shear strength of an SP soil should increase with the addition of rainfall up to a point of near saturation. Beyond this point the shear strength will again decrease. However, during this study the maximum simulated rainfall amount applied to the sand was not enough to show an increase in strength.

Rainfall Effects on Traction

For all of the vehicles on firm soil the most significant reduction in D/W_{20} occurs between the dry condition and only 1/4 inch of rainfall. However, the soils for these tests were firm as shown in the soil data summary (Table 2). This process allowed little or no time for infiltration of the rainfall, which generally did not permit appreciable strength changes. The surface layer or a thin surface film of very wet soil served as the lubricating mechanism in these tests and sinkages were negligible. A comparison of Figures 14-16, which are plots of the D/W_{20} values versus rainfall for each vehicle on each soil type, shows that the traction loss with rainfall is more appreciable for the LAV25 and the HEMTT (wheeled vehicles) than for the M113A1 (tracked vehicle). The LAV25 on the CH soil dropped from a D/W_{20} value of 0.70 for the dry condition to a value of 0.16 for the 1/4-inch rainfall increment. This is a 77 percent loss in traction from the dry condition. The HEMTT had similar results, dropping from a D/W_{20} value of 0.49 to 0.15, or a 69 percent loss in traction, while the M113A1 dropped from 0.50 to 0.20, or a drop of 60 percent.

In WES studies the drawbar pull coefficient on level ground is considered to be approximately equal to the slope that a vehicle can

COMPOSITE OF SOIL TYPES

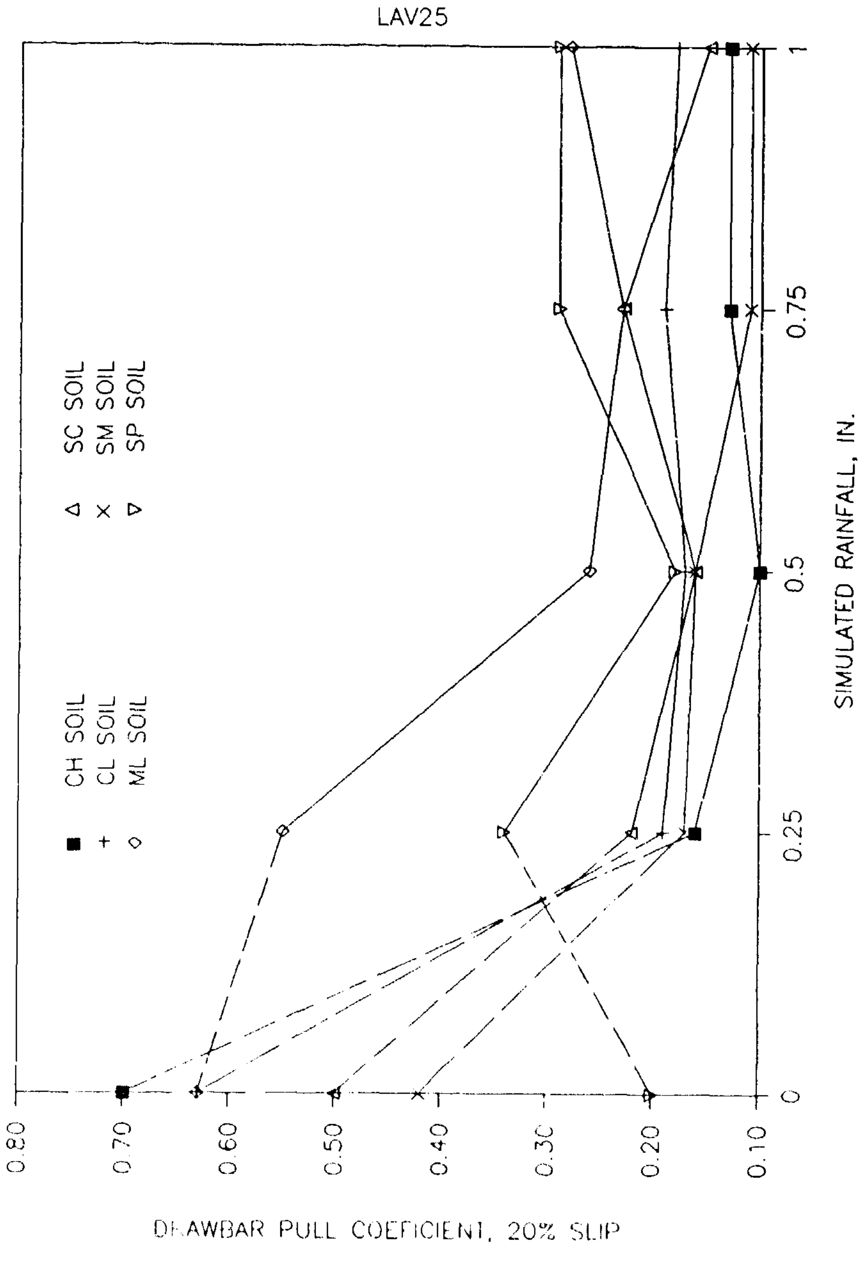


Figure 14. LAV25, Rainfall Effects on Traction

COMPOSITE OF SOIL TYPES

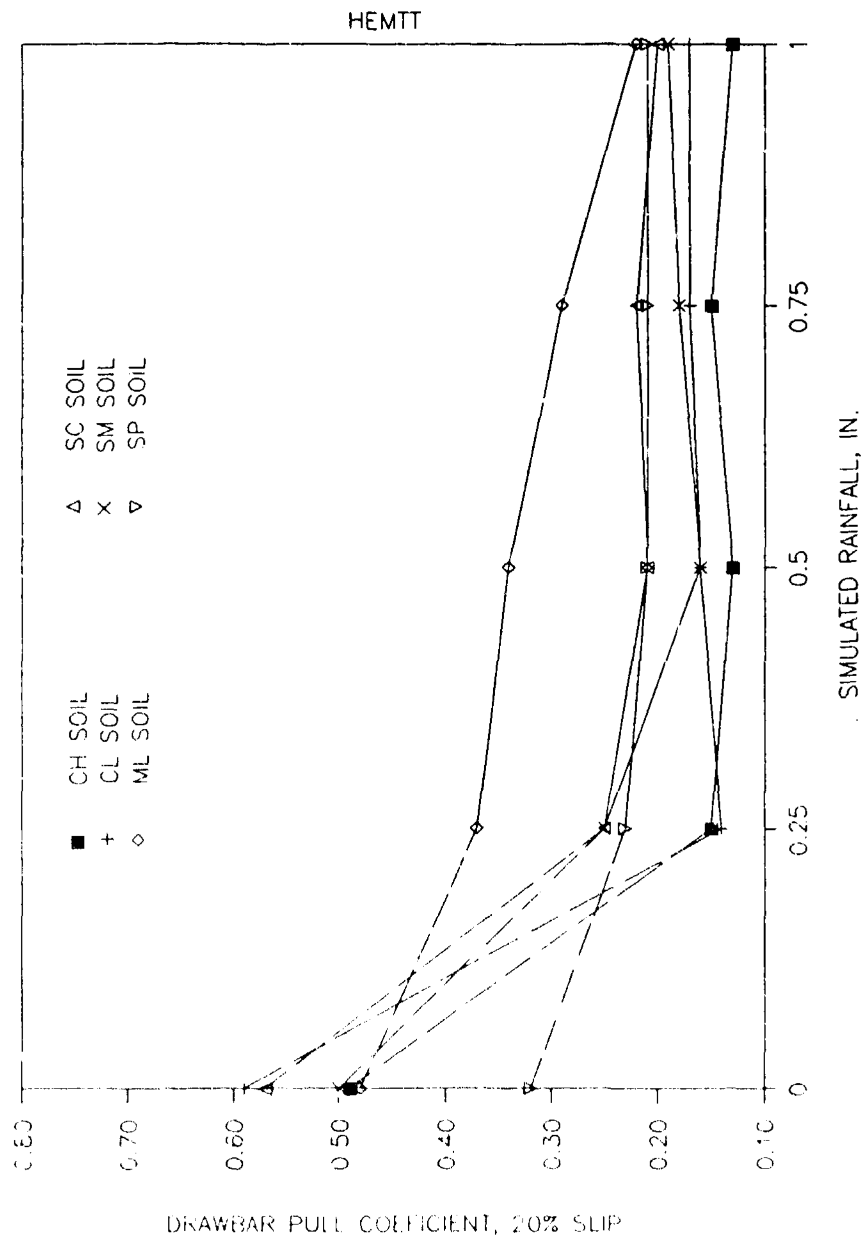


Figure 15. HEMTT, Rainfall Effects on Traction

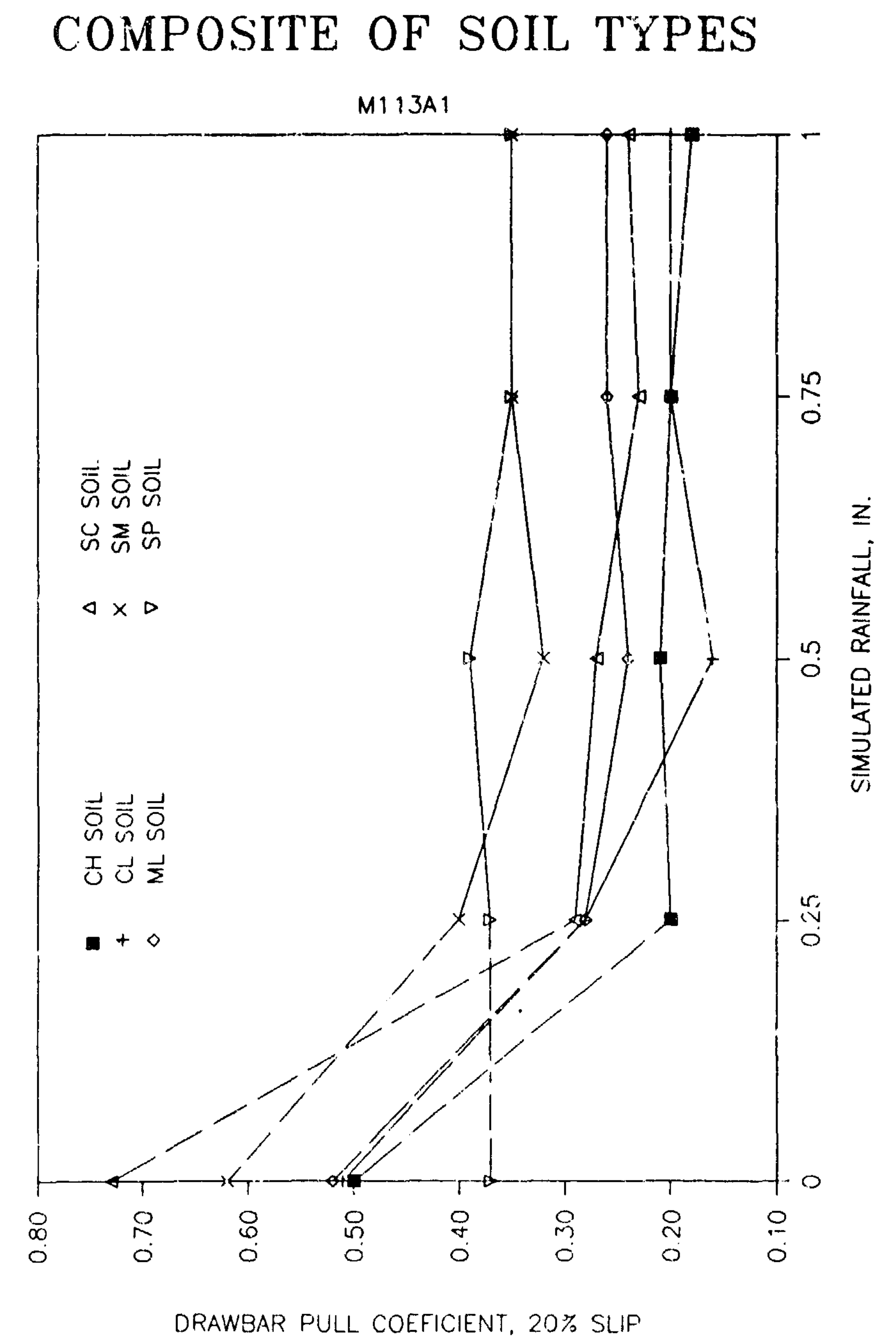


Figure 16. M113A1, Rainfall Effects on Traction

negotiate for the same soil conditions. If we apply this approximation to these conditions, these results would indicate that the vehicles would not be able to negotiate slopes on a CH soil greater than 20 percent after 1/4 inch of rainfall. However, since a CH soil is an alluvial material, it rarely occurs on steep slopes while many of the other soils do occur quite often. Therefore, the traction loss due to incremental rainfall can be detrimental to the off road performance of military vehicles in most fine-grained soils.

An example of how the information from this study can be used is illustrated in the terrain data for an area of the central region of the Federal Republic of Germany. According to terrain data gathered for the Fulda Quadrangle, which is representative of the central region, the percentage of area occupied by different ranges of slope are shown below.

Fulda Quadrangle

Slopes	Percent of Total Area
≦2	10
>2-5	16
>5-10	30
>10-20	14
>20-40	15
>40-60	9
>60-70	3
>70	3

The Fulda Quadrangle is 98 percent fine-grained soil. When the area is dry, the vehicles in this study could negotiate 94 percent (100-3-3) of the total area, not considering slopes greater than 60 percent.

However, if the area were wetted with 1/4 inch of rainfall, the vehicles would only be able to negotiate approximately 70 percent (10 + 16 + 30 + 14) of the area if slope is the only terrain variable. Such information can be very helpful to the military planners in times of crisis.

Summary

The purpose of this study was to investigate a means of quantifying the loss of traction on firm soils associated with soil type and rainfall amounts. The firm soils allowed only negligible vehicle sinkage, insuring results in which traction was not governed by mass soil properties of the base layer, but by moisture effects on the surface of the soil. Eighty traction tests were used for the study with three state-of-the-art military vehicles, two wheeled and one tracked, on CH, CL, ML, SC, SM, and SP soils over a range of simulated rainfall conditions, from the dry condition and increasing in 1/4-inch rainfall increments to a maximum of 1 inch or the point at which the vehicle performance did not substantially change from one wetting to the next. Soils data were collected for adequate soil descriptions and soil strength data were obtained with the WES cone penetrometer, which is the standard instrument used by WES to determine field soil strengths for trafficability tests. Correlations of loss of traction in terms of drawbar pull coefficients (drawbar pull/vehicle weight) and rainfall amounts were developed for values of vehicle slip from 0-100 percent slip. It was found that the drawbar pull coefficient-slip curve follows the path of a rectangular hyperbola and can be expressed mathematically by an equation of the form:

$$y = \frac{x}{mx + b}$$

All of the drawbar pull tests were reduced in this manner to produce a family of curves relative to rainfall-vehicle-soil type. These curves were used to determine the drawbar pull coefficient at 20 percent vehicle slip for each increment of simulated rainfall. The optimum work output occurs at or near 20 percent vehicle slip. Results of this study indicate that the greatest loss in traction for most soil types is between the dry condition and 1/4 inch of rainfall. The more clay fraction in the soil the more traction loss can be expected with rainfall. Also, the traction loss is more appreciable for the wheeled vehicles than for the tracked vehicle. The results of this study could prove useful for the military and private industry when more extensive testing is analyzed.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of the investigation reported herein, the following conclusions can be made:

- a. A reasonably accurate prediction can be made of the traction loss on, or a reduction in surface shear strength of, various soil types by the addition of surface water. This can be accomplished by properly describing the rainfall equivalent, soil type, and type of vehicle (wheeled or tracked).
- b. The greatest loss in traction on most soil types occurs between the dry condition and 1/4 inch of rainfall. After this the traction loss only drops slightly and then seems to level out with additional rainfall.
- c. The more clay fraction in the soil, the more traction loss can be expected with rainfall within the scope of variables defined in this study.
- d. The traction loss is more appreciable for the wheeled vehicles than for the tracked vehicle.

Recommendations

Based on the results of this study it is recommended that an analysis be made of additional vehicles and varied vehicle configurations.

This should include varying tire pressures and tire sizes for the wheeled vehicles to determine what can be done to improve wheeled vehicle performances and to enhance the mobility of future wheeled vehicles. Also, it is recommended that the track pads be removed from tracked vehicles to determine the increase in traction that can be developed with a more aggressive track and if it would be worthwhile or feasible to design tracked vehicles with easily removable track pads.

BIBLIOGRAPHY

1. Measuring Soil Properties in Vehicle Mobility Research; N. R. Murphy; US Army Engineer Waterways Experiment Station, Vicksburg, MS, TR No. 3-652, Report 2, Oct 1965.

2. A Study of the Effects of Wet Surface Soil Conditions on the Performance of a Single Pneumatic-Tired Wheel; J. L. Smith; US Army Engineer Waterways Experiment Station, Vicksburg, MS, TR 3-703, Nov 1965.

3. Foundation Engineering; R. Peck, W. E. Hanson and T. H. Thornburn; Wiley and Sons, NY, 1974.

4. Trafficability of Soils, Nineteenth Supplement; E. S. Rush and J. H. Robinson; US Army Engineer Waterways Experiment Station, Vicksburg, MS, TM 3-250, Apr 1971.

5. Physical Properties of Soils; R. E. Means and J. V. Parcher; Merrill Publishing, Columbus, OH, 1963.

6. Mobility Assessment of the Heavy Expanded Mobility Tactical Truck (HEMTT) - Initial Production Vehicles; B. G. Schreiner, D. W. Moore, and K. Grimes; US Army Engineer Waterways Experiment Station, Vicksburg, MS, TR GL-85-4, Apr 1985.

7. Probability and Statistics for Engineers; I. Miller and J. Freund; Prentice-Hall, Inc., Englewood Cliffs, NJ, 1977.

Table 1

Drawbar Pull Coefficients, 20 Percent Vehicle Slip

Vehicle	Dry	Simulated Rainfall, in. 1/4-in.	1/2-in.	3/4-in.	1 in.
			CH		
LAV25	0.70	0.16	0.10	0.13	0.13
HEMTT	0.49	0.15	0.13	0.15	0.13
M113A1	0.50	0.20	0.21	0.20	0.18
Average	0.56	0.17	0.15	0.16	0.15
			CL		
LAV25	0.63	0.19	0.17	0.19	0.18
HEMTT	0.59	0.14	0.16	0.17	0.17
M113A1	0.51	0.28	0.16	0.20	0.20
Average	0.58	0.20	0.16	0.19	0.18
			ML		
LAV25	0.63	0.55	0.26	0.23	0.28
HEMTT	0.48	0.37	0.34	0.29	0.22
M113A1	0.52	0.28	0.24	0.26	0.26
Average	0.54	0.40	0.28	0.26	0.25
			SC		
LAV25	0.50	0.22	0.16	0.23	0.15
HEMTT	0.57	0.25	0.21	0.22	0.20
M113A1	0.73	0.29	0.27	0.23	0.24
Average	0.60	0.25	0.21	0.23	0.20
			SM		
LAV25	0.42	0.17	0.16	0.11	0.11
HEMTT	0.50	0.25	0.16	0.18	0.19
M113A1	0.62	0.40	0.32	0.35	0.35
Average	0.51	0.27	0.21	0.21	0.22
			SP		
LAV25	0.20	0.34	0.18	0.29	0.29
HEMTT	0.32	0.23	0.21	0.21	0.21
M113A1	0.37	0.37	0.39	0.35	0.35
Average	0.30	0.31	0.26	0.28	0.28

TABLE 2

SUMMARY OF SOILS DATA

VEHICLE	LOCATION	SOIL TYPE	SIMULATED RAINFALL	AVERAGE CONE INDEX OF LAYERS, IN.			MOISTURE CONTENT AT DEPTH, IN. PERCENT DRY WEIGHT (%)		
				SFC	0-6	6-12	SFC	3	6
LAV25	DUCKPORT	CH	DRY	203	286	300	10.75	26.2	25.9
			1/4"	132	274	300	33.65	26.2	25.9
			1/2"	77	259	300	51.8	26.2	25.9
			3/4"	67	256	300	40.65	26.2	25.9
			1"	64	247	300	52.5	26.2	25.9
LAV25	DUCKPORT	CL	DRY	179	249	300	24.6	24.55	23.15
			1/4"	103	214	281	29.05	24.55	23.15
			1/2"	92	216	286	44.15	24.55	23.15
			3/4"	56	197	283	36.25	24.55	23.15
			1"	59	211	287	43.85	24.55	23.15
LAV25	LeTOURNEAU	ML	DRY	284	298	300	4.05	16.65	16.6
			1/4"	278	297	300	21.45	17.95	14.95
			1/2"	194	285	300	22.5	22.1	19.75
			3/4"	152	276	300	26.5	25.55	26.6
			1"	70	265	300	39.65	28.01	19.05
LAV25	FT CHAFFEE	SC	DRY	286	298	300	8.1	18.2	19.5
			1/4"	285	298	300	32.3	16.5	16.2
			1/2"	263	294	300	33.8	17.7	19.01
			3/4"	266	295	300	30.95	22.75	19.01
			1"	279	297	300	34.55	16.45	19.01
LAV25	FT CHAFFEE	SM	DRY	136	134	300	13.8	21.05	18.55
			1/4"	77	203	300	30.25	22.65	18.75
			1/2"	115	214	300	34.25	20.15	18.55
			3/4"	76	208	300	26.45	21.4	18.55
			1"	186	263	300	28.3	21.45	18.55
LAV25	DUCKPORT	SP	DRY	9	65	204	0.4	0.6	0.5
			1/4"	21	118	253	23.3	5.5	2.5
			1/2"	27	107	255	24.6	7.8	8.4
			3/4"	27	114	262	26.2	22.8	22.2

(Continued)

(Sheet 1 of 3)

TABLE 2

SUMMARY OF SOILS DATA

VEHICLE	LOCATION	SOIL TYPE	SIMULATED RAINFALL	AVERAGE CONE INDEX OF LAYERS, IN.			MOISTURE CONTENT AT DEPTH, IN. PERCENT DRY WEIGHT (%)		
				SFC	0-6	6-12	SFC	3	6
HEMTT	DUCKPORT	CH	DRY	300	300	300	6.25	21.35	24.15
			1/4"	177	280	300	42.7	29.9	24.8
			1/2"	153	273	300	42.85	23.75	24.75
			3/4"	203	284	300	51.2	36.7	27.45
			1"	265	295	300	53.2	33.2	24.8
HEMTT	DUCKPORT	CL	DRY	285	296	300	9.01	15.5	17.5
			1/4"	155	281	300	35.6	29.1	19.1
			1/2"	99	265	300	35.85	17.5	17.5
			3/4"	82	259	300	37.1	15.5	17.5
			1"	56	258	300	33.85	15.5	17.5
HEMTT	LeTOURNEAU	ML	DRY	184	280	300	25.55	16.2	16.55
			1/4"	229	290	300	26.2	16.2	16.55
			1/2"	235	291	300	27.55	16.2	16.55
			3/4"	152	276	300	26.5	16.2	16.55
			1"	114	272	300	41.2	16.2	16.55
HEMTT	FT CHAFFEE	SC	DRY	300	300	300	23.3	12.01	14.25
			1/4"	274	295	300	25.8	14.65	16.2
			1/2"	300	300	300	41.8	16.6	16.8
			3/4"	300	300	300	22.8	16.75	16.8
			1"	266	294	300	19.75	16.1	16.2
HEMTT	FT CHAFFEE	SM	DRY	136	276	300	18.8	17.35	19.5
			1/4"	94	270	300	25.7	20.5	19.5
			1/2"	77	187	300	50.85	21.35	19.5
			3/4"	72	215	300	31.3	21.05	19.5
			1"	25	127	201	35.45	18.9	19.5
HEMTT	DUCKPORT	SP	DRY	20	110	267	0.6	4.4	4.6
			1/4"	28	146	289	20.7	5.5	4.7
			1/2"	33	159	300	19.4	8.9	5.3

(Continued)

(Sheet 2 of 3)

TABLE 2

SUMMARY OF SOILS DATA

VEHICLE	LOCATION	SOIL TYPE	SIMULATED RAINFALL	AVERAGE CONE INDEX OF LAYERS, IN.			MOISTURE CONTENT AT DEPTH, IN. PERCENT DRY WEIGHT (%)		
				SFC	0-6	6-12	SFC	3	6
M113A1	DUCKPORT	CH	DRY	300	300	300	6.25	21.35	24.15
			1/4"	160	280	300	34.65	24.25	22.1
			1/2"	143	270	300	34.1	30.35	24.3
			3/4"	159	275	300	42.25	32.85	26.2
			1"	127	270	300	61.2	49.3	27.3
M113A1	DUCKPORT	CL	DRY	300	300	300	5.8	17.95	16.15
			1/4"	227	289	300	32.25	27.5	21.45
			1/2"	124	271	300	35.05	26.45	21.15
			3/4"	152	274	300	39.3	31.9	24.8
			1"	115	267	300	43.75	32.1	28.8
M113A1	LeTOURNEAU	ML	DRY	291	299	300	17.5	14.85	18.2
			1/4"	222	289	300	32.25	26.55	21.45
			1/2"	128	275	300	34.9	26.4	22.7
			3/4"	209	286	300	32.9	25.05	24.85
M113A1	FT CHAFFEE	SC	DRY	300	300	300	4.35	15.9	14.1
			1/4"	228	289	300	27.25	13.35	14.1
			1/2"	134	273	300	26.95	16.05	14.1
			3/4"	160	280	300	29.55	17.1	14.1
			1"	208	286	300	28.35	16.65	14.1
M113A1	FT CHAFFEE	SM	DRY	218	288	300	4.25	14.01	15.2
			1/4"	101	264	300	16.75	14.25	15.2
			1/2"	45	256	300	16.75	25.3	15.2
			3/4"	96	250	300	20.7	21.45	15.2
M113A1	DUCKPORT	SP	DRY	21	99	250	4.7	11.2	14.3
			1/4"	33	105	216	20.01	2.1	7.9
			1/2"	21	78	204	25.01	19.8	25.9
			3/4"	27	107	262	24.4	23.01	23.7

(Sheet 3 of 3)

Table 3

Drawbar Pull Test Results

Load lb	DBP Coe Pull/Weight	Slip Percent
	LAV25, Duckport, Louisiana, CH Soil	
Normal condition, TMR = 1,000 lb		
4,000	0.15	1.2
5,000	0.19	1.0
8,000	0.30	2.7
10,000	0.37	5.1
11,000	0.41	1.8
12,000	0.45	3.0
14,000	0.52	7.0
15,000	0.56	9.2
16,000	0.59	13.2
18,000	0.67	15.2
19,000	0.71	25.3
22,000	0.82	100.0
0.25 in. Simulated rainfall, TMR = 1,000 lb		
2,000	0.07	8.2
3,000	0.11	9.2
4,000	0.15	13.7
5,000	0.19	22.3
5,000	0.19	23.3
5,000	0.19	36.6
5,000	0.19	38.0
5,000	0.19	24.0
6,000	0.22	43.9
6,000	0.22	52.9
7,000	0.26	55.4
7,000	0.26	72.6
7,000	0.26	73.0
8,000	0.30	81.9
8,000	0.30	100.0
0.50 in. Simulated rainfall, TMR = 1,200 lb		
800	0.03	5.2
800	0.03	5.8
2,000	0.07	8.2

(Continued)

(Sheet 1 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in. Simulated rainfall, TMR = 1,200 lb (Continued)		
2,800	0.10	19.4
3,200	0.12	15.2
3,200	0.12	33.5
3,600	0.13	41.4
4,000	0.15	32.0
4,000	0.15	44.5
4,000	0.15	55.2
4,800	0.18	56.6
5,000	0.19	45.4
5,600	0.21	54.3
6,000	0.22	73.5
6,400	0.24	100.0
0.75 in. Simulated rainfall, TMR = 1,200 lb		
600	0.02	1.0
1,600	0.06	10.7
2,000	0.07	6.3
2,000	0.07	11.0
2,400	0.09	12.2
2,800	0.10	15.8
3,200	0.12	26.2
3,200	0.12	26.3
3,200	0.12	20.7
3,600	0.13	19.8
3,600	0.13	21.3
4,000	0.15	19.9
4,000	0.15	34.6
4,800	0.18	28.9
4,800	0.18	43.2
5,600	0.21	60.6
6,000	0.22	48.3
6,000	0.22	59.7
6,000	0.22	84.7
6,600	0.25	100.0
7,000	0.26	75.7
7,000	0.26	100.0

(Continued)

(Sheet 2 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.00 in. Simulated rainfall, TMR = 1,500 lb		
800	0.03	1.0
1,000	0.04	7.5
2,000	0.07	15.0
2,000	0.07	13.2
2,40	0.09	8.2
2,800	0.10	14.9
3,000	0.11	18.9
3,200	0.12	11.8
4,000	0.15	16.4
4,000	0.15	31.2
4,800	0.18	32.6
5,200	0.19	38.2
5,600	0.21	40.6
5,600	0.21	54.8
6,000	0.22	46.3
6,000	0.22	56.6
6,000	0.22	66.7
6,000	0.22	100.0
7,200	0.27	66.7
8,000	0.30	90.8
LAV25, Duckport, Louisiana, CL Soil		
Normal condition, TMR = 1,100 lb		
5,000	0.19	1.3
8,000	0.30	6.1
10,000	0.37	7.0
10,000	0.37	2.8
13,000	0.48	7.7
13,000	0.48	7.8
15,000	0.56	10.3
15,000	0.56	12.6
17,000	0.63	16.3
18,000	0.67	17.3
19,000	0.71	32.6
20,000	0.74	100.0
21,000	0.78	100.0

(Continued)

(Sheet 3 of 42)

Table 3

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 1,200 lb		
2,000	0.07	3.9
3,000	0.11	8.5
4,000	0.15	12.1
5,000	0.19	11.0
5,000	0.19	23.0
5,000	0.19	34.1
7,000	0.26	55.3
8,000	0.30	75.5
9,000	0.33	100.0
10,000	0.37	72.1
10,000	0.37	100.0
0.50 in. Simulated rainfall, TMR = 1,600 lb		
1,200	0.04	3.8
2,000	0.07	7.2
2,000	0.07	10.8
3,200	0.12	9.1
4,000	0.15	11.3
4,000	0.15	15.8
5,200	0.19	19.4
6,000	0.22	24.0
6,000	0.22	31.5
7,200	0.27	47.2
8,000	0.30	59.5
8,000	0.30	77.0
8,500	0.32	100.0
9,000	0.33	100.0
0.75 in. Simulated rainfall, TMR = 1,800 lb		
1,600	0.06	4.4
2,000	0.07	7.8
2,400	0.09	6.8
3,200	0.12	9.9
4,000	0.15	12.0
5,200	0.19	15.5
6,000	0.22	21.1
6,000	0.22	23.8

(Continued)

(Sheet 4 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 1,800 lb (Continued)		
6,000	0.22	27.5
7,200	0.27	33.1
7,200	0.27	35.3
8,000	0.30	56.5
8,000	0.30	70.7
8,000	0.30	86.6
8,400	0.31	100.0
1.00 in. Simulated rainfall, TMR = 1,800 lb		
2,000	0.07	3.5
3,200	0.12	14.1
3,200	0.12	14.5
4,000	0.15	15.8
4,000	0.15	16.5
6,000	0.22	23.6
6,000	0.22	30.7
7,200	0.27	30.5
7,200	0.27	57.5
8,000	0.30	71.6
8,000	0.30	76.5
9,200	0.34	39.5
9,200	0.34	100.0
LAV25, LeTourneau, Mississippi, ML Soil		
Normal condition, TMR = 800 lb		
3,000	0.11	1.8
4,000	0.15	2.0
5,000	0.19	2.1
8,000	0.30	2.7
9,000	0.33	3.0
9,500	0.35	3.0
12,000	0.45	3.8
12,000	0.45	4.8
13,500	0.50	5.4
15,000	0.56	6.3
16,000	0.59	5.7
16,000	0.59	6.8

(Continued)

(Sheet 5 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 800 lb (Continued)		
16,500	0.61	16.7
17,500	0.65	14.3
18,000	0.67	35.5
18,000	0.67	40.5
19,000	0.71	44.4
20,000	0.74	100.0
0.25 in. Simulated rainfall, TMR = 900 lb		
3,200	0.12	1.2
4,400	0.16	1.0
5,700	0.21	1.8
6,800	0.25	3.8
8,000	0.30	4.3
9,500	0.35	5.0
10,400	0.39	7.4
11,700	0.44	6.3
12,500	0.46	13.0
12,900	0.48	19.4
14,600	0.54	21.1
15,300	0.57	33.3
16,000	0.59	39.4
16,500	0.61	33.3
17,500	0.65	100.0
18,500	0.69	100.0
0.50 in. Simulated rainfall, TMR = 1,000 lbs		
1,000	0.04	1.9
1,300	0.05	4.8
2,500	0.09	4.4
4,000	0.15	5.1
4,000	0.15	5.4
5,700	0.21	12.5
6,500	0.24	7.9
7,500	0.28	9.1
7,500	0.28	30.8
8,600	0.32	34.2
9,500	0.35	44.4

(Continued)

(Sheet 6 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in. Simulated rainfall, TMR = 1,000 lbs (Continued)		
10,100	0.38	16.7
10,500	0.39	100.0
10,900	0.41	100.0
1.00 in. Simulated rainfall, TMR = 1,800 lb		
1,000	0.04	2.4
2,300	0.09	4.8
3,400	0.13	6.3
5,200	0.19	14.3
6,600	0.25	25.0
7,000	0.26	26.8
7,500	0.28	16.7
7,800	0.29	51.4
8,400	0.31	61.5
8,500	0.32	25.9
9,000	0.33	62.5
10,000	0.37	76.9
11,500	0.43	100.0
12,100	0.45	100.0
1.50 in. Simulated rainfall, TMR = 1,800 lb		
700	0.03	1.8
2,000	0.07	3.5
3,500	0.13	2.4
4,600	0.17	7.9
5,500	0.20	8.2
5,500	0.20	12.3
6,900	0.26	9.1
8,300	0.31	21.9
9,000	0.33	45.8
10,000	0.37	23.1
10,000	0.37	54.5
10,300	0.38	100.0
14,000	0.52	100.0

(Continued)

(Sheet 7 of 42)

Table 3 (Continued)

Load lb	DBF Coe Pull/Weight	Slip Percent
LAV25, Fort Chaffee, Arkansas, SC Soil		
Normal condition, TMR = 1,250 lb		
1,000	0.04	3.5
1,300	0.05	3.4
6,500	0.24	4.6
9,000	0.33	6.3
9,000	0.33	7.0
10,800	0.40	12.2
11,500	0.43	12.5
13,000	0.48	12.0
15,000	0.56	16.3
15,500	0.58	18.8
16,500	0.61	19.7
20,000	0.74	22.3
20,300	0.75	100.0
21,500	0.80	100.0
3,000	0.11	3.3
6,000	0.22	5.6
12,000	0.45	10.0
12,000	0.45	10.6
15,000	0.56	13.0
17,400	0.65	16.5
18,000	0.67	26.0
18,000	0.67	20.3
19,200	0.71	41.2
19,800	0.74	25.3
21,000	0.78	32.0
21,000	0.78	100.0
22,200	0.83	100.0
0.25 in. Simulated rainfall, TMR = 1,100 lb		
2,500	0.09	9.1
3,800	0.14	10.0
5,000	0.19	12.4
7,500	0.28	21.4
8,000	0.30	47.4
9,500	0.35	39.7
9,500	0.35	50.3
9,500	0.35	67.1

(Continued)

(Sheet 8 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 1,100 lb (Continued)		
9,500	0.35	62.8
9,500	0.35	68.1
10,000	0.37	86.3
10,500	0.39	74.1
10,500	0.39	87.0
11,000	0.41	100.0
13,000	0.48	100.0
0.50 in. Simulated rainfall, TMR = 1,200 lb		
1,500	0.06	10.3
5,000	0.19	17.2
6,500	0.24	26.9
7,000	0.26	40.2
8,000	0.30	58.0
8,000	0.30	41.5
8,000	0.30	68.3
8,000	0.30	72.0
9,000	0.33	88.1
9,000	0.33	84.0
9,000	0.33	78.1
9,000	0.33	100.0
9,000	0.33	100.0
0.75 in. Simulated rainfall, TMR = 1,200 lb		
5,000	0.19	12.3
6,000	0.22	18.9
7,000	0.26	29.4
7,500	0.28	41.1
8,500	0.32	45.0
9.000	0.33	59.9
9,500	0.35	76.2
9,500	0.35	84.2
9,500	0.35	40.1
9,500	0.35	64.2
10,000	0.37	80.8
10,000	0.37	85.8
10,000	0.37	100.0
10,000	0.37	100.0

(Continued)

(Sheet 9 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.00 in. Simulated rainfall, TMR = 1,100 lb		
2,000	0.07	12.3
4,500	0.17	20.1
6,500	0.24	27.9
6,500	0.24	33.5
7,000	0.26	[illegible]7.8
7,000	0.26	56.1
9,000	0.33	72.6
9,000	0.33	83.4
9,000	0.33	86.9
9,500	0.35	64.8
9,500	0.35	78.1
9,500	0.35	100.0
10,500	0.39	82.5
11,000	0.41	100.0
LAV25, Fort Chaffee, Arkansas, SM Soil		
Normal condition, TMR = 2,000 lb		
5,500	0.20	3.6
7,500	0.28	5.8
9,500	0.35	9.3
10,000	0.37	84.8
11,000	0.41	13.0
11,000	0.41	70.6
11,500	0.43	19.1
11,500	0.43	100.0
12,000	0.45	100.0
12,500	0.46	13.0
13,000	0.48	48.4
15,000	0.56	36.4
16,000	0.59	49.3
0.25 in. Simulated rainfall, TMR = 1,700 lb		
5,000	0.19	9.9
5,500	0.20	60.6
6,000	0.22	15.9
6,500	0.24	69.0
7,000	9.26	70.1

(Continued)

(Sheet 10 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 1,700 lb (Continued)		
7,500	0.28	76.3
7,500	0.28	69.3
8,000	0.30	72.3
9,000	0.33	87.1
10,000	0.37	100.0
10,500	0.39	100.0
0.50 in. Simulated rainfall, TMR = 1,800 lb		
3,000	0.11	3.4
4,500	0.17	21.0
4,500	0.17	62.3
5,000	0.19	63.3
6,000	0.22	73.1
6,500	0.24	49.7
6,500	0.24	81.5
6,500	0.24	100.0
7,000	0.26	64.7
7,000	0.26	72.2
7,500	0.28	91.6
7,500	0.28	100.0
8,000	0.30	84.5
0.75 in. Simulated rainfall, TMR = 1,900 lb		
3,500	0.13	18.5
5,000	0.19	72.6
5,000	0.19	74.8
5,500	0.20	53.4
5,500	0.20	82.3
6,500	0.24	64.2
6,500	0.24	75.1
6,500	0.24	88.0
7,500	0.28	100.0
8,500	0.32	77.3
9,000	0.33	100.0
9,500	0.35	88.6

(Continued)

(Sheet 11 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
LAV25, Duckport, Louisiana, SP Soil		
Normal condition, TMR = 2,200 lb		
1,200	0.04	4.7
5,200	0.18	4.1
7,600	0.27	100.0
3,600	0.13	2.1
4,500	0.16	1.6
7,400	0.26	100.0 (Stalled)
0.25 in. Simulated rainfall, TMR = 2,500 lb		
2,900	0.10	1.6
4,500	0.16	2.1
8,500	0.30	0.4
10,400	0.37	100.0 (Stalled)
0.50 in. Simulated rainfall, TMR = 2,800 lb		
400	0.01	4.5
1,600	0.06	2.0
2,400	0.09	2.2
4,500	0.16	5.2
7,600	0.27	1.9
8,000	0.28	11.0
10,000	0.35	100.0 (Stalled)
0.75 in. Simulated rainfall, no TMR		
2,400	0.09	4.1
4,400	0.16	6.1
4,800	0.17	9.1
5,800	0.21	5.0
7,400	0.26	4.1
11,400	0.40	100.0 (Stalled)

(Continued)

(Sheet 12 of 42)

Table 3 (Continued)

Load lb	D3P Coe Pull/Weight	Slip Percent
10 Ton HEMTT, Duckport, Louisiana, CH Soil		
Normal condition, TMR = 1,700 lb		
10,000	0.17	8.0
13,000	0.22	1.6
14,000	0.23	4.0
15,000	0.25	21.5
17,000	0.28	3.4
17,000	0.28	41.6
18,000	0.30	5.4
19,000	0.32	4.6
20,000	0.33	13.5
22,000	0.37	5.0
23,000	0.38	7.5
26,000	0.43	5.6
29,000	0.48	9.1
29,000	0.48	9.4
30,000	0.50	11.3
34,000	0.57	14.2
35,000	0.58	18.8
39,000	0.65	27.5
39,000	0.65	72.6
39,000	0.65	100.0
40,000	0.67	52.2
40,000	0.67	22.7
41,000	0.68	79.2
42,000	0.70	35.4
42,000	0.70	48.6
42,000	0.70	36.2
49,000	0.81	100.0
0.25 in. Simulated rainfall, TMR = 2,000 lb		
9,000	0.15	16.2
10,000	0.17	47.2
10,000	0.17	26.4
10,000	0.17	26.3
10,000	0.17	26.4
10,000	0.17	20.3
11,000	0.18	85.9
11,000	0.18	48.2
11,000	0.18	36.1

(Continued)

(Sheet 13 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 2,000 lb (Continued)		
12,000	0.20	31.5
12,000	0.20	41.2
12,000	0.20	39.7
12,000	0.20	48.1
13,000	0.22	40.1
13,000	0.22	44.9
14,000	0.23	53.2
14,000	0.23	58.5
14,000	0.23	80.4
14,000	0.23	100.0
15,000	0.25	67.6
15,000	0.25	87.2
17,000	0.28	100.0
0.50 in. Simulated rainfall, TMR = 2,500 lb		
5,000	0.08	13.5
6,000	0.10	9.7
7,000	0.12	20.9
8,000	0.13	21.1
8,000	0.13	22.5
8,000	0.13	26.5
9,000	0.15	22.0
9,000	0.15	32.9
10,000	0.17	34.3
11,000	0.18	42.9
13,000	0.22	35.3
13,000	0.22	46.2
13,000	0.22	44.2
15,000	0.25	61.9
15,000	0.25	79.2
16,000	0.27	79.7
16,000	0.27	100.0
17,000	0.28	100.0
0.75 in. Simulated rainfall, TMR = 3,000 lb		
10,000	0.17	19.6
10,000	0.17	20.0

(Continued)

(Sheet 14 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 3,000 lb (Continued)		
10,000	0.17	23.2
10,000	0.17	29.2
10,000	0.17	25.8
11,000	0.18	26.9
11,000	0.18	19.5
11,500	0.19	27.8
11,500	0.19	26.1
12,000	0.20	34.0
13,000	0.22	36.4
13,000	0.22	43.9
14,000	0.23	47.8
15,000	0.25	43.6
15,000	0.25	46.7
15,000	0.25	49.6
15,000	0.25	50.3
15,000	0.25	32.5
15,000	0.25	67.1
15,000	0.25	69.3
15,000	0.25	74.9
16,000	0.27	40.7
16,000	0.27	69.6
17,000	0.28	56.9
17,000	0.28	51.7
18,000	0.30	71.6
18,000	0.30	87.5
18,000	0.30	56.0
19,000	0.32	61.0
20,000	0.33	72.0
20,000	0.33	80.1
20,000	0.33	78.4
22,000	0.37	82.1
26,000	0.43	100.0
1.00 in. Simulated rainfall, TMR = 3,000 lb		
7,000	0.12	17.0
10,000	0.17	26.2
10,000	0.17	29.6
10,000	0.17	37.1
11,000	0.18	31.0

(Continued)

(Sheet 15 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.00 in. Simulated rainfall, TMR = 3,000 lb (Continued)		
12,000	0.20	29.4
12,000	0.20	36.8
12,000	0.20	46.3
13,000	0.22	34.0
15,000	0.25	42.9
15,000	0.25	53.7
17,000	0.28	63.5
17,000	0.28	74.4
17,000	0.28	72.1
18,000	0.30	88.2
19,000	0.32	64.5
19,000	0.32	100.0
20,000	0.33	69.9
23,000	0.38	87.6
23,000	0.38	100.0
25,000	0.42	100.0
10 Ton HEMTT, Duckport, Louisiana, CL Soil		
Normal condition, TMR = 1,800 lb		
7,000	0.12	5.8
11,000	0.18	1.0
12,000	0.20	1.5
12,000	0.20	2.7
13,000	0.22	1.0
15,000	0.25	8.7
15,000	0.25	4.9
17,500	0.29	1.4
18,000	0.30	5.5
19,000	0.32	6.9
19,000	0.32	2.7
20,000	0.33	2.6
20,000	0.33	7.6
22,000	0.37	7.0
23,000	0.38	9.1
24,000	0.40	4.0
25,000	0.42	8.2
26,000	0.43	13.6
28,000	0.47	18.8

(Continued)

(Sheet 16 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 1,800 lb (Continued)		
30,000	0.50	9.0
31,000	0.52	18.8
32,000	0.53	18.8
34,000	0.57	5.9
35,000	0.58	11.4
39,000	0.65	15.9
39,000	0.65	21.7
43,000	0.71	27.5
47,000	0.78	100.0
50,000	0.83	100.0
0.25 in. Simulated rainfall, TMR = 3,000 lb		
8,000	0.13	23.3
10,000	0.17	20.6
10,000	0.17	22.9
10,000	0.17	30.1
11,000	0.18	46.0
12,000	0.20	17.8
12,000	0.20	39.1
12,000	0.20	49.3
13,000	0.22	54.5
14,000	0.23	24.5
14,000	0.23	52.7
15,000	0.25	63.3
15,000	0.25	56.8
16,000	0.27	68.0
17,000	0.28	76.1
17,000	0.28	70.1
18,000	0.30	74.7
19,000	0.32	82.2
19,000	0.32	100.0
19,000	0.32	82.1
22,000	0.37	100.0
0.50 in. Simulated rainfall, TMR = 3,000 lb		
8,000	0.13	18.0
10,000	0.17	20.3

(Continued)

(Sheet 17 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in. Simulated rainfall, TMR = 3,000 lb (Continued)		
10,000	0.17	17.3
10,000	0.17	27.7
10,000	0.17	26.6
11,000	0.18	27.9
12,000	0.20	29.4
12,000	0.20	24.2
13,000	0.22	30.9
13,000	0.22	25.6
14,000	0.23	40.3
15,000	0.25	35.9
17,000	0.28	39.1
17,000	0.28	48.1
19,000	0.32	62.1
20,000	0.33	77.9
20,000	0.33	56.4
22,000	0.37	75.9
23,000	0.38	100.0
24,000	0.40	100.0
0.75 in. Simulated rainfall, TMR = 3,500 lb		
7,000	0.12	18.8
8,000	0.13	18.8
8,000	0.13	18.8
9,000	0.15	19.4
9,000	0.15	18.8
10,000	0.17	21.0
10,000	0.17	23.3
10,000	0.17	20.7
11,000	0.18	22.1
12,000	0.20	21.2
14,000	0.23	26.4
15,000	0.25	30.8
15,000	0.25	29.2
17,000	0.28	32.4
17,000	0.28	32.0
19,000	0.32	40.1
20,000	0.33	46.7
21,000	0.35	47.7
23,000	0.38	66.6

(Continued)

(Sheet 18 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 3,500 lb (Continued)		
23,000	0.38	56.5
24,000	0.40	73.6
27,000	0.45	72.6
27,000	0.45	100.0
27,000	0.45	100.0
1.00 in. Simulated rainfall, TMR = 3,500 lb		
6,000	0.10	12.4
6,000	0.10	14.6
7,000	0.12	24.8
8,000	0.13	22.0
8,000	0.13	10.7
8,000	0.13	17.7
9,000	0.15	17.8
9,000	0.15	13.0
10,000	0.17	13.4
12,000	0.20	22.2
13,000	0.22	22.0
15,000	0.25	31.3
15,000	0.25	29.0
18,000	0.30	34.6
19,000	0.32	34.9
20,000	0.33	40.0
22,000	0.37	49.9
23,000	0.38	48.1
24,000	0.40	50.2
26,000	0.43	75.6
26,000	0.43	100.0
27,000	0.45	100.0
10 Ton HEMTT, LeTourneau, Mississippi, ML Soil		
Normal condition, TMR = 500 lb		
9,000	0.15	3.2
9,500	0.16	2.6
10,500	0.17	3.2
12,500	0.21	4.2
12,500	0.21	4.0

(Continued)

(Sheet 19 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 500 lb (Continued)		
13,500	0.22	5.1
17,000	0.28	4.8
17,000	0.28	7.2
18,500	0.31	5.0
20,000	0.33	9.3
20,000	0.33	10.1
21,000	0.35	9.3
22,000	0.37	13.8
24,500	0.41	16.4
26,000	0.43	15.8
26,000	0.43	17.1
27,000	0.45	16.9
31,000	0.52	26.7
32,000	0.53	30.3
33,000	0.55	31.2
33,500	0.56	27.1
38,500	0.64	100.0
39,000	0.65	100.0
0.25 in Simulated rainfall, TMR = 800 lb		
8,000	0.13	2.3
9,500	0.16	3.8
10,000	0.17	5.4
10,000	0.17	5.7
13,000	0.22	6.5
15,000	0.25	7.3
15,000	0.25	8.5
18,000	0.30	12.3
22,000	0.37	14.3
22,000	0.37	14.0
23,000	0.38	19.4
23,500	0.39	19.4
26,000	0.43	24.4
26,500	0.44	100.0
27,000	0.45	25.6
28,000	0.47	100.0
28,500	0.47	25.6

(Continued)

(Sheet 20 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in Simulated rainfall, TMR = 1,000 lb		
3,000	0.05	1.1
5,000	0.08	2.1
5,000	0.08	2.1
10,000	0.17	6.2
11,000	0.18	7.8
12,500	0.21	8.4
16,000	0.27	12.6
17,000	0.28	13.6
19,500	0.32	17.1
20,000	0.33	17.5
22,000	0.37	21.9
22,500	0.37	19.4
25,000	0.42	29.4
25,000	0.42	100.0
28,000	0.47	100.0
30,000	0.50	32.8
0.75 in. Simulated rainfall, TMR = 1,200 lb		
3,000	0.05	3.2
6,000	0.10	5.1
10,500	0.17	8.3
12,500	0.21	13.1
13,000	0.22	9.9
14,000	0.23	12.0
15,000	0.25	14.0
16,000	0.27	14.6
17,000	0.28	19.4
17,000	0.28	17.3
20,000	0.33	22.3
21,500	0.36	25.6
24,000	0.40	41.3
25,500	0.42	29.4
28,500	0.47	100.0
29,000	0.48	100.0
1.25 in. Simulated rainfall, TMR = 1,800 lb		
2,000	0.03	3.8
3,000	0.05	5.1

(Continued)

(Sheet 21 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.25 in. Simulated rainfall, TMR = 1,800 lb (Continued)		
3,000	0.05	6.3
6,000	0.10	6.9
7,500	0.12	9.6
10,000	0.17	10.7
10,000	0.17	11.2
13,500	0.22	14.9
14,000	0.23	14.9
15,500	0.26	16.6
16,500	0.27	19.4
17,000	0.28	25.6
17,500	0.29	25.1
19,000	0.32	34.0
22,500	0.37	48.7
26,000	0.43	100.0
28,000	0.47	100.0
1.50 in. Simulated rainfall, TMR = 2,000 lb		
4,000	0.07	4.7
4,500	0.07	5.9
7,500	0.12	11.4
8,000	0.13	13.4
10,000	0.17	14.3
11,000	0.18	13.4
12,000	0.20	16.7
12,500	0.21	15.3
15,000	0.25	17.4
16,000	0.27	19.4
19,000	0.32	23.4
20,000	0.33	24.7
23,000	0.38	44.1
23,500	0.39	29.4
27,000	0.45	100.0
28,000	0.47	100.0
28,500	0.47	35.5

(Continued)

(Sheet 22 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
10 Ton HEMTT, Fort Chaffee, Arkansas, SC Soil		
Normal condition, TMR = 2,800 lb		
8,000	0.13	1.4
20,000	0.33	6.0
27,000	0.45	7.8
30,000	0.50	15.5
31,000	0.52	12.4
35,000	0.58	22.8
36,000	0.60	51.3
36,000	0.60	54.9
37,000	0.62	77.2
37,000	0.62	23.9
38,000	0.63	29.2
38,000	0.63	41.3
38,000	0.63	100.0
40,000	0.67	61.0
40,000	0.67	100.0
43,000	0.71	42.3
43,000	0.71	55.6
0.25 in Simulated rainfall, TMR = 2,800 lb		
5,000	0.08	2.7
10,000	0.17	12.2
13,000	0.22	16.9
15,000	0.25	13.3
16,000	0.27	24.1
17,000	0.28	19.6
18,000	0.30	41.1
20,000	0.53	63.8
20,000	0.33	37.7
23,000	0.38	47.1
24,000	0.40	59.0
26,000	0.43	65.0
29,000	0.48	65.0
31,000	0.52	79.5
32,000	0.52	100.0
35,000	0.58	100.0

(Continued)

(Sheet 23 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in. Simulated rainfall, TMR = 2,800 lb		
5,000	0.08	2.1
9,000	0.15	9.1
15,000	0.25	26.8
15,000	0.25	22.4
16,000	0.27	35.4
16,000	0.27	52.5
17,000	0.28	64.4
19,000	0.32	70.4
20,000	0.33	54.4
21,000	0.35	80.6
22,000	0.37	60.0
22,000	0.37	78.8
24,000	0.40	87.2
25,000	0.42	100.0
31,000	0.52	100.0
0.75 in. Simulated rainfall, TMR = 3,000 lb		
11,000	0.18	6.3
14,000	0.23	15.8
18,000	0.30	43.5
18,000	0.30	36.0
20,000	0.33	48.8
20,000	0.33	59.9
20,000	0.33	59.0
21,000	0.35	83.4
22,000	0.37	69.0
24,000	0.40	78.2
31,000	0.52	100.0
31,000	0.52	100.0
1.00 in. Simulated rainfall, TMR = 3,000 lb		
6,000	0.10	7.9
14,000	0.23	18.0
17,000	0.28	34.9
19,000	0.32	48.8
20,000	0.33	69.7
20,000	0.33	40.6

(Continued)

(Sheet 24 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.00 in. Simulated rainfall, TMR = 3,000 lb (Continued)		
21,000	0.35	83.4
21,000	0.35	56.7
23,000	0.38	68.3
24,000	0.40	85.2
25,000	0.42	90.8
29,000	0.48	100.0
29,000	0.48	100.0
10 Ton HEMTT, Fort Chaffee, Arkansas, SM Soil		
Normal condition, TMR = 3,800 lb		
11,000	0.18	2.9
13,200	0.22	5.4
17,000	0.28	6.9
21,000	0.35	7.5
22,800	0.38	4.1
26.700	0.44	7.2
28,600	0.48	10.0
30,200	0.50	52.2
30,300	0.50	7.2
31,800	0.53	13.0
32,000	0.53	31.7
32,200	0.54	100.0
32,800	0.55	10.9
33,700	0.56	18.0
35,800	0.60	23.2
36,000	0.60	24.1
36,000	0.60	100.0
0.25 in. Simulated rainfall, TMR = 4,200 lb		
10,500	0.17	6.9
13,000	0.22	7.5
13,800	0.23	14.9
14,400	0.24	13.1
15,800	0.26	19.8
16,000	0.27	28.7
17,000	0.28	40.4
17,100	0.28	60.6

(Continued)

(Sheet 25 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 4,200 lb (Continued)		
17,800	0.30	68.5
17,800	0.30	85.7
18,000	0.30	31.7
19,000	0.32	53.4
19,200	0.32	60.3
20,000	0.33	100.0
21,000	0.35	66.4
25,200	0.42	69.3
28,000	0.47	100.0
0.50 in. Simulated rainfall, TMR = 4,000 lb		
7,200	0.12	13.7
13,100	0.22	20.0
14,000	0.23	35.3
14,100	0.23	36.3
14,500	0.24	48.8
15,000	0.25	63.3
16,700	0.28	67.6
17,000	0.28	36.0
17,000	0.28	69.4
18,100	0.30	47.7
18,200	0.30	59.8
18,700	0.31	67.6
18,700	0.31	78.1
20,000	0.33	60.0
20,700	0.34	66.8
24,000	0.40	100.0
25,000	0.42	100.0
0.75 in. Simulated rainfall, TMR = 4,200 lb		
10,800	0.18	14.9
13,000	0.22	27.7
14,800	0.25	28.1
15,100	0.25	69.3
15,300	0.25	70.7
15,800	0.26	40.2
16,000	0.27	75.1

(Continued)

(Sheet 26 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 4,200 lb (Continued)		
17,200	0.29	40.0
19,000	0.32	53.8
20,000	0.33	79.0
20,200	0.34	55.9
24,500	0.41	60.0
27,000	0.45	100.0
28,000	0.47	100.0
1.00 in. Simulated rainfall, TMR = 4,200 lb		
9,100	0.15	12.2
10,000	0.17	15.9
10,200	0.17	18.0
11,300	0.19	16.2
12,300	0.20	20.7
13,800	0.23	25.5
14,700	0.24	59.7
14,900	0.25	66.7
14,900	0.25	34.4
15,000	0.25	46.3
15,000	0.25	26.4
15,200	0.25	41.4
16,700	0.28	56.5
17,400	0.29	75.9
18,000	0.30	58.2
18,000	0.30	72.1
18,300	0.30	100.0
21,000	0.35	100.0
10 Ton HEMTT, Duckport, Louisiana, SP Soil		
Normal condition, TMR = 6,300 lb		
10,000	0.17	7.8
15,000	0.25	18.0
15,000	0.25	5.4
16,000	0.27	15.2
20,000	0.33	24.1
21,000	0.35	24.1
22,000	0.36	14.6

(Continued)

(Sheet 27 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 6,300 lb (Continued)		
24,000	0.40	19.8
24,500	0.41	100.0 (Bouncing)
0.25 in. Simulated rainfall, TMR = 2,500 lb		
7,000	0.12	20.7
8,000	0.13	18.0
11,000	0.18	14.6
18,000	0.30	8.9
21,000	0.35	12.2
22,000	0.36	12.2
24,000	0.40	20.3
24,500	0.41	100.0 (Bouncing)
0.50 in. Simulated rainfall, no TMR		
5,000	0.08	21.2
6,000	0.10	18.0
9,000	0.15	13.7
14,000	0.23	18.0
16,000	0.27	18.0
20,000	0.33	31.7
19,000	0.31	10.9
19,500	0.32	27.7
19,000	0.31	18.0
20,000	0.33	27.7
20,000	0.33	14.6
20,500	0.34	100.0
M113A1, Duckport, Louisiana, CH Soil		
Normal condition, TMR = 2,000 lb		
4,000	0.17	3.1
4,500	0.19	6.3
4,500	0.19	4.0
5,500	0.24	8.9
6,500	0.28	9.1
7,500	0.32	11.6

(Continued)

(Sheet 28 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 2,000 lb (Continued)		
8,500	0.36	11.7
10,000	0.43	16.4
10,500	0.45	16.9
13,000	0.56	19.2
13,500	0.58	27.3
15,000	0.64	21.9
16,000	0.68	41.4
16,000	0.68	31.6
16,500	0.71	59.5
16,500	0.71	41.4
17,500	0.75	100.0
18,000	0.77	100.0
0.25 in. Simulated rainfall, TMR = 2,500 lb		
2,000	0.09	2.6
3,000	0.13	4.2
3,000	0.13	8.9
3,500	0.15	8.7
3,500	0.15	14.6
4,000	0.17	21.9
4,000	0.17	25.6
4,500	0.19	31.3
5,000	0.21	39.0
5,500	0.24	39.1
5,500	0.24	66.4
5,500	0.24	85.4
6,000	0.26	53.4
6,000	0.26	100.0
7,000	0.30	57.0
8,500	0.36	85.6
9,000	0.38	78.3
9,000	0.38	100.0
9,500	0.41	54.0
10,500	0.45	64.7
11,000	0.47	59.7

(Continued)

(Sheet 29 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in. Simulated rainfall, TMR = 2,000 lb		
2,500	0.11	4.8
3,000	0.13	6.3
5,000	0.21	8.9
5,000	0.21	23.8
5,000	0.21	38.9
5,000	0.21	42.3
5,000	0.21	51.9
5,000	0.21	64.9
5,000	0.21	74.7
5,000	0.21	91.9
5,500	0.24	25.1
6,000	0.26	82.6
6,000	9.26	100.0
6,000	0.26	100.0
6,500	0.28	32.7
6,500	0.28	60.4
7,500	0.32	69.6
0.75 in. Simulated rainfall, TMR = 2,000 lb		
2,500	0.11	6.3
3,000	0.13	17.8
3,500	0.15	3.7
4,000	0.17	31.6
4,000	0.17	48.3
4,500	0.19	100.0
5,000	0.21	94.1
5,000	0.21	72.8
5,500	0.24	82.2
5,500	0.24	100.0
6,000	0.26	12.1
6,000	9.26	35.5
7,000	0.30	29.7
7,000	0.30	42.6
7,000	0.30	77.8
7,500	0.32	75.1

(Continued)

(Sheet 30 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.00 in. Simulated rainfall, TMR = 2,000 lb		
3,500	0.15	10.4
3,500	0.15	20.6
4,000	0.17	15.0
4,500	0.19	32.1
5,000	0.21	27.1
5,000	0.21	85.1
5,000	0.21	95.3
5,500	0.24	70.6
5,500	0.24	38.1
5,500	0.24	63.8
6,000	0.26	82.8
6,000	0.26	55.6
6,000	0.26	100.0
6,500	0.28	59.2
6,500	0.28	100.0
7,000	0.30	88.0
7,000	0.30	94.0
M113A1, Duckport, Louisiana, CL Soil		
Normal condition, TMR = 1,500 lb		
3,000	0.13	3.0
3,500	0.15	6.7
5,000	0.21	8.4
6,500	0.28	9.2
8,000	0.34	8.1
8,500	0.36	13.2
9,500	0.41	10.7
12,500	0.53	18.5
13,500	0.58	14.8
14,500	0.62	19.8
15,000	0.64	17.8
15,000	0.64	21.9
16,500	0.71	21.9
17,000	0.73	27.5
17,000	0.73	53.1
17,500	0.75	59.2
19,000	0.81	100.0

(Continued)

(Sheet 31 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 1,500 lb		
2,000	0.09	4.7
5,000	0.21	8.1
5,500	0.24	10.2
5,500	0.24	25.5
7,000	0.30	10.4
7,000	0.30	39.5
7,500	0.32	16.7
7,500	0.32	27.7
8,000	0.34	52.1
8,500	0.36	44.5
8,500	0.36	66.2
9,000	0.38	53.1
9,500	0.41	83.7
9,500	0.41	100.0
10,000	0.43	79.9
10,000	0.43	100.0
10,500	0.45	56.6
0.50 in. Simulated rainfall, TMR = 2,000 lb		
1,000	0.04	12.8
2,000	0.09	6.3
2,500	0.11	15.0
4,000	0.17	18.6
4,000	0.17	12.5
4,500	0.19	19.6
4,500	0.19	23.4
5,000	0.21	41.9
5,500	0.24	68.8
6,000	0.26	28.6
6,000	0.26	86.8
6,000	0.26	93.0
6,000	0.26	100.0
6,500	0.28	100.0
7,000	0.30	74.0
8,000	0.34	31.2
8,000	0.34	58.6
8,000	0.34	69.6
8,000	0.34	82.1

(Continued)

(Sheet 32 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 2,000 lb		
2,000	0.09	5.0
2,500	0.11	4.1
4,000	0.17	18.4
4,500	0.19	6.3
4,500	0.19	11.2
5,000	0.21	21.9
5,000	0.21	24.1
5,000	0.21	32.3
5,000	0.21	55.6
5,500	0.24	65.0
5,500	0.24	76.5
6,000	0.26	38.2
6,000	0.26	42.7
6,000	0.26	52.9
6,500	0.28	79.7
6,500	0.28	100.0
7,000	0.30	68.3
7,000	0.30	80.5
7,500	0.32	89.4
9,000	0.38	100.0
M113A1, LeTourneau, Mississippi, ML Soil		
Normal condition, TMR = 1,200 lb		
6,000	0.26	6.3
7,200	0.31	2.1
7,600	0.32	16.7
7,600	0.32	20.8
11,200	0.48	10.7
12,400	0.53	20.0
12,800	0.55	15.0
13,200	0.56	25.0
13,200	0.56	24.0
14,400	0.62	17.1
14,800	0.63	42.0
15,200	0.65	25.7
15,600	0.67	32.1
16,000	0.68	35.7
16,000	0.68	43.5

(Continued)

(Sheet 33 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 1,200 lb (Continued)		
17,200	0.74	100.0
18,000	0.77	100.0
0.25 in. Simulated rainfall, TMR = 1,600 lb		
6,000	0.26	8.7
6,000	0.26	61.2
6,000	0.26	61.1
6,400	0.27	44.6
6,400	0.27	65.2
6,800	0.29	70.9
6,800	0.29	58.7
6,800	0.29	85.1
6,800	0.29	59.6
6,800	0.29	62.0
6,800	0.29	13.3
7,200	0.31	59.7
7,200	0.31	67.1
7,200	0.31	78.2
8,400	0.36	73.5
8,400	0.36	44.2
8,800	0.38	69.8
9,200	0.39	15.6
9,200	0.39	26.3
0.50 in. Simulated rainfall, TMR = 1,600 lb		
4,800	0.21	10.7
5,200	0.22	25.0
5,600	0.24	41.4
6,000	0.26	14.0
6,000	0.26	18.6
6,000	0.26	38.6
6,000	0.26	41.9
6,400	0.27	52.2
6,400	0.27	86.3
6,400	0.27	11.9
7,200	0.31	69.3
7,200	0.31	50.0

(Continued)

(Sheet 34 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.50 in. Simulated rainfall, TMR = 1,600 lb (Continued)		
7,200	0.31	25.0
7,200	0.31	30.4
7,600	0.32	19.4
7,600	0.32	22.2
8,000	0.34	66.7
8,000	0.34	73.2
8,000	0.34	87.5
8,400	0.36	78.9
10,000	0.43	100.0
11,200	0.48	100.0
0.75 in. Simulated rainfall, TMR = 1,600 lb		
5,200	0.22	21.7
5,200	0.22	26.7
5,200	0.22	20.0
5,200	0.22	34.3
5,200	0.22	23.1
5,600	0.24	25.0
5,600	0.24	63.5
6,000	0.26	78.7
6,000	0.26	46.6
6,000	0.26	9.1
6,400	0.27	17.3
6,400	0.27	100.0
6,800	0.29	71.2
6,800	0.29	57.7
7,200	0.31	44.4
7,200	0.31	33.3
7,600	0.32	40.8
7,600	0.32	44.8
7,600	0.32	61.8
7,600	0.32	47.1
7,600	0.32	50.6
M113A1, Fort Chaffee, Arkansas, SC Soil		
Normal condition, TMR = 1,400 lb		
10,500	0.45	2.8
13,500	0.58	4.8

(Continued)

(Sheet 35 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
Normal condition, TMR = 1,400 lb (Continued)		
14,000	0.60	2.1
14,000	0.60	5.9
16,500	0.71	12.1
16,500	0.71	20.1
17,000	0.73	24.6
17,500	0.75	18.4
17,500	0.75	34.8
17,500	0.75	100.0
18,500	0.79	22.6
18,500	0.79	100.0
0.25 in. Simulated rainfall, TMR = 1,650 lb		
5,000	0.21	6.8
5,000	0.21	17.3
7,000	0.30	28.2
8,000	0.34	13.9
8,000	0.34	43.8
8,000	0.34	72.2
8,000	0.34	100.0
9,500	0.41	45.6
10,500	0.45	100.0
0.50 in. Simulated rainfall, TMR = 1,800 lb		
4,000	0.17	1.7
5,000	0.21	8.7
5,000	0.21	12.0
6,000	0.26	20.5
6,500	0.28	54.8
6,500	0.28	71.2
7,000	0.30	29.2
7,000	0.30	37.1
7,000	0.30	85.4
8,000	0.34	49.4
8,000	0.34	100.0
8,500	0.36	69.9
8,500	0.36	79.9
9,500	0.41	100.0

(Continued)

(Sheet 36 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 1,800 lb		
4,000	0.17	6.0
5,000	0.21	11.2
5,000	0.21	24.8
6,000	0.26	68.5
6,500	0.28	22.7
6,500	0.28	43.2
6,500	0.28	76.9
7,000	0.30	44.0
7,000	0.30	63.6
7,000	0.30	70.4
7,500	0.32	100.0
8,000	0.34	100.0
1.00 in. Simulated rainfall, TMR = 1,900 lb		
5,000	0.21	5.6
5,000	0.21	6.5
5,500	0.24	28.6
6,000	0.26	20.2
6,500	0.28	21.7
6,500	0.28	34.7
6,500	0.28	37.7
7,000	0.30	45.0
7,500	0.32	57.4
8,000	0.34	61.7
9,000	0.38	50.8
10,000	0.43	100.0
11,000	0.47	100.0
3,500	0.15	2.0
4,500	0.19	17.9
6,000	0.26	13.8
6,000	0.26	34.5
6,000	0.26	49.1
7,000	0.30	31.9
7,000	0.30	59.8
7,000	0.30	72.7
7,500	0.32	60.0
7,500	0.32	83.1
8,500	0.36	43.9
8,500	0.36	53.3

(Continued)

(Sheet 37 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
1.00 in. Simulated rainfall, TMR = 1,900 lb (Continued)		
8,500	0.36	100.0
9,500	0.41	100.0
M113A1, Fort Chaffee, Arkansas, SM Soil		
Normal condition, TMR = 1,750 lb		
12,400	0.53	5.0
12,800	0.55	7.2
13,400	0.57	12.0
13,600	0.58	52.7
14,000	0.60	9.0
14,000	0.60	100.0
14,800	0.63	46.6
16,000	0.68	9.4
20,000	0.85	100.0
Normal condition, TMR = 1,600 lb		
6,000	0.26	3.4
8,500	0.36	4.6
9,400	0.40	2.3
10,000	0.43	8.1
13,000	0.56	7.4
14,500	0.62	24.4
15,000	0.64	14.8
15,000	0.64	34.0
15,200	0.65	100.0
21,000	0.90	100.0
Normal condition, TMR = 1,700 lb		
5,200	0.22	2.3
10,000	0.43	6.3
12,300	0.53	7.3
13,600	0.58	5.3
14,400	0.62	8.9
16,400	0.70	19.9
20,000	0.85	100.0

(Continued)

(Sheet 38 of 42)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 2,000 lb		
4,800	0.21	2.3
6,800	0.29	4.0
7,000	0.30	4.1
8,000	0.34	24.2
8,500	0.36	4.3
9,300	0.40	8.1
9,600	0.41	10.1
9,600	0.41	34.4
10,000	0.43	13.2
10,100	0.43	100.0
10,500	0.45	100.0
0.50 in. Simulated rainfall, TMR = 2,000 lb		
4,200	0.18	6.1
5,400	0.23	5.0
6,000	0.26	10.4
6,500	0.28	8.1
7,300	0.31	8.8
7,500	0.32	40.3
7,900	0.34	34.4
8,000	0.34	64.5
8,400	0.36	42.8
8,800	0.38	11.8
9,000	0.38	100.0
10,000	0.43	100.0
0.75 in. Simulated rainfall, TMR = 2,100 lb		
5,000	0.21	3.0
5,500	0.24	3.6
6,000	0.26	11.1
6,700	0.29	21.9
7,200	0.31	4.6
7,300	0.31	20.3
8,000	0.34	13.2
8,500	0.36	30.9
9,000	0.38	13.2
9,200	0.39	50.7

(Continued)

Table 3 (Continued)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 2,100 lb (Continued)		
9,400	0.40	62.8
9,600	0.41	12.4
9,700	0.41	100.0
9,700	0.41	100.0
M113A1, Duckport, Louisiana, SP Soil		
Normal condition, TMR = 2,200 lb		
4,400	0.18	15.7
6,000	0.24	4.2
7,600	0.31	9.0
8,000	0.32	27.9
9,000	0.36	23.4
9,800	0.39	23.4
10,200	0.41	31.0
11,000	0.44	41.1
11,000	0.44	16.4
10,600	0.43	32.9
13,000	0.52	8.0
14,600	0.59	14.8
Drier normal condition, TMR = 1,800 lb		
5,600	0.23	3.2
7,400	0.30	5.1
8,000	0.32	14.8
10,200	0.41	30.3
11,000	0.44	48.9
11,400	0.46	56.2
12,100	0.49	58.2
12,600	0.51	60.7
13,000	0.52	61.7
0.25 in. Simulated rainfall, TMR = 2,500 lb		
2,000	0.08	6.3
2,600	0.10	4.2
3,600	0.14	3.2
4,300	0.19	6.3

(Continued)

(Sheet 40 of 42)

Table 3 (Continued)

Load lb	DBP Coe Full/Weight	Slip Percent
0.25 in. Simulated rainfall, TMR = 2,500 lb (Continued)		
6,300	0.25	4.2
8,400	0.34	8.0
8,600	0.35	16.4
9,600	0.39	34.3
10,800	0.43	27.0
11,200	0.45	23.4
12,100	0.49	17.5
11,600	0.47	31.9
11,200	0.45	41.6
10,000	0.40	34.3
8,400	0.34	14.8
8,400	0.34	16.4
12,200	0.49	40.4
12,800	0.51	36.1
0.50 in. Simulated rainfall, TMR = 3,000 lb		
2,000	0.08	0.8
3,200	0.13	6.3
4,000	0.16	5.7
4,400	0.18	5.7
4,600	0.19	2.5
6,000	0.24	8.0
8,000	0.32	4.2
9,000	0.36	18.9
10,000	0.40	23.4
11,600	0.47	29.3
12,000	0.48	23.4
12,600	0.51	28.5
10,400	0.42	37.6
9,600	0.39	23.4
8,000	0.32	16.4
7,200	0.29	12.4
7,200	0.29	9.8
0.75 in. Simulated rainfall, TMR = 2,000 lb		
2,000	0.08	3.2
2,800	0.11	2.5

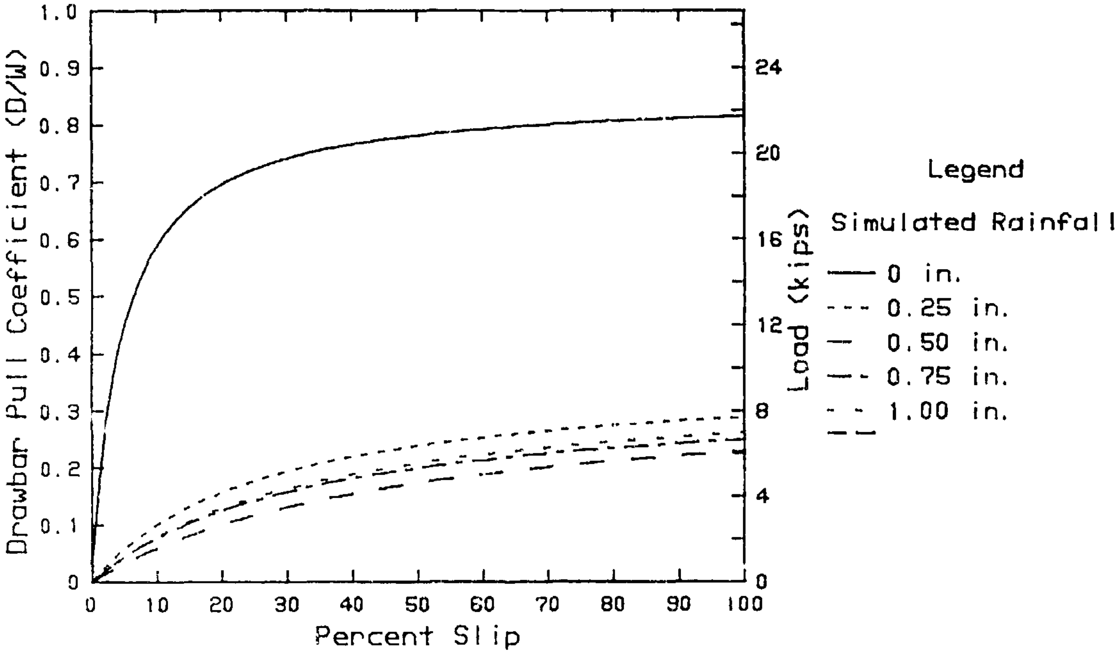
(Continued)

(Sheet 41 of 42)

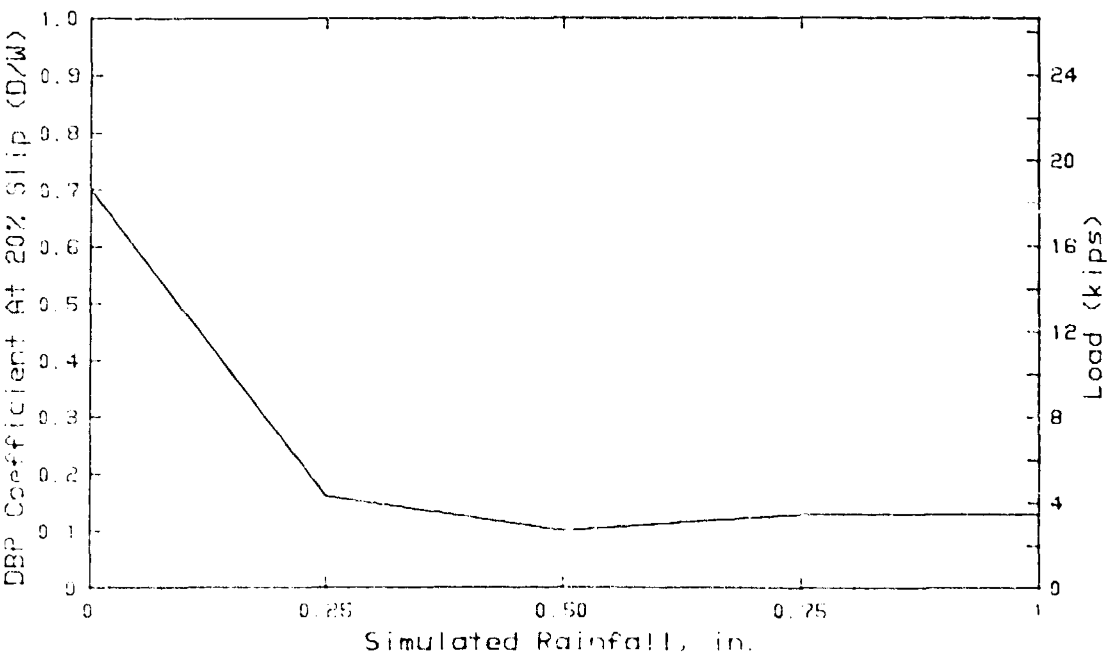
Table 3 (Concluded)

Load lb	DBP Coe Pull/Weight	Slip Percent
0.75 in. Simulated rainfall, TMR = 2,000 lb (Continued)		
3,200	0.13	5.7
4,000	0.16	4.2
5,200	0.21	6.3
6,800	0.27	6.3
8,000	0.32	8.0
9,200	0.37	13.8
10,400	0.42	19.7
10,000	0.40	5.7
11,600	0.47	13.8
10,400	0.42	27.9
9,400	0.38	40.4
8,400	0.34	32.4
6,400	0.26	7.1
6,800	0.27	4.2

(Sheet 42 of 42)



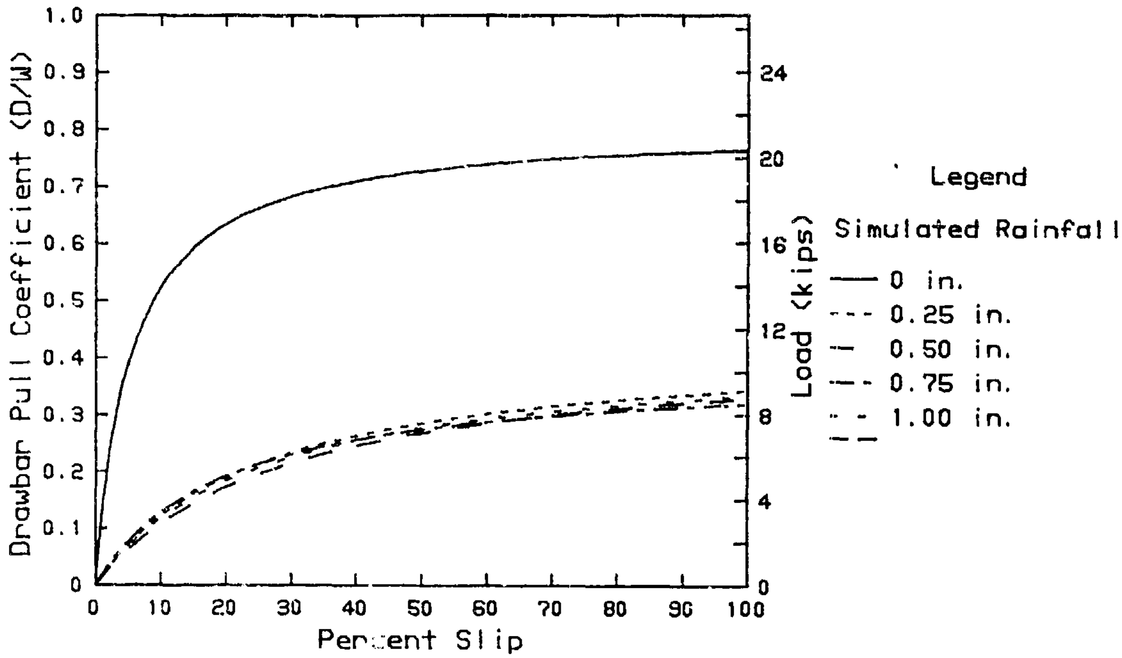
Drawbar Pull Tests



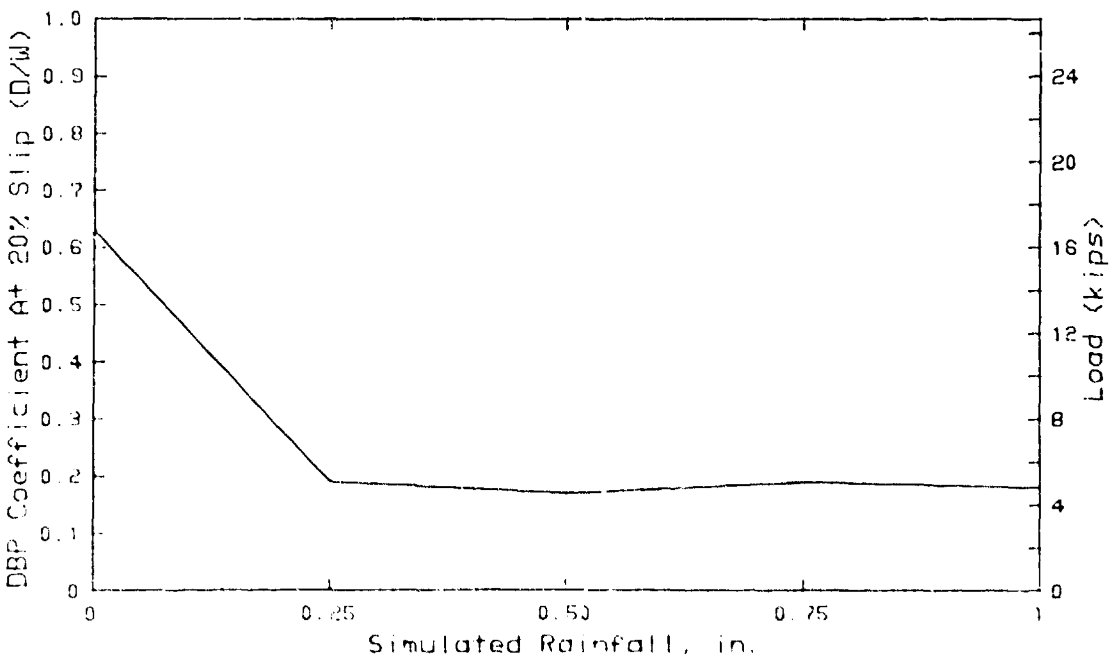
20%, Drawbar Pull Coefficient

LAV25; Duckport, La; CH Soil

Plate 1



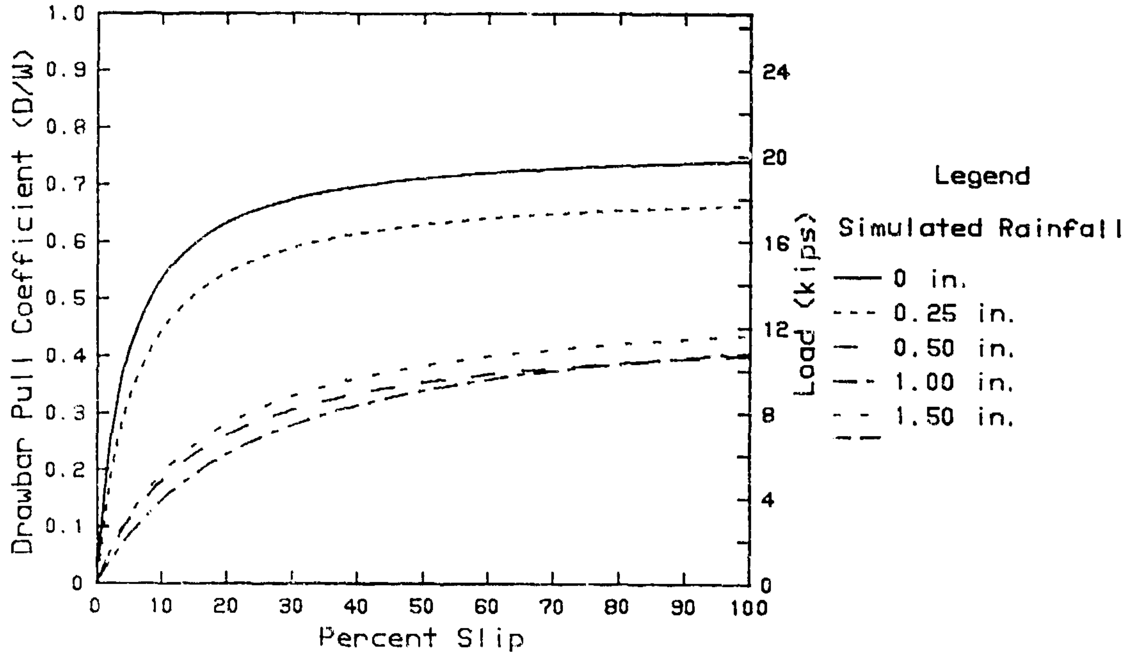
Drawbar Pull Tests



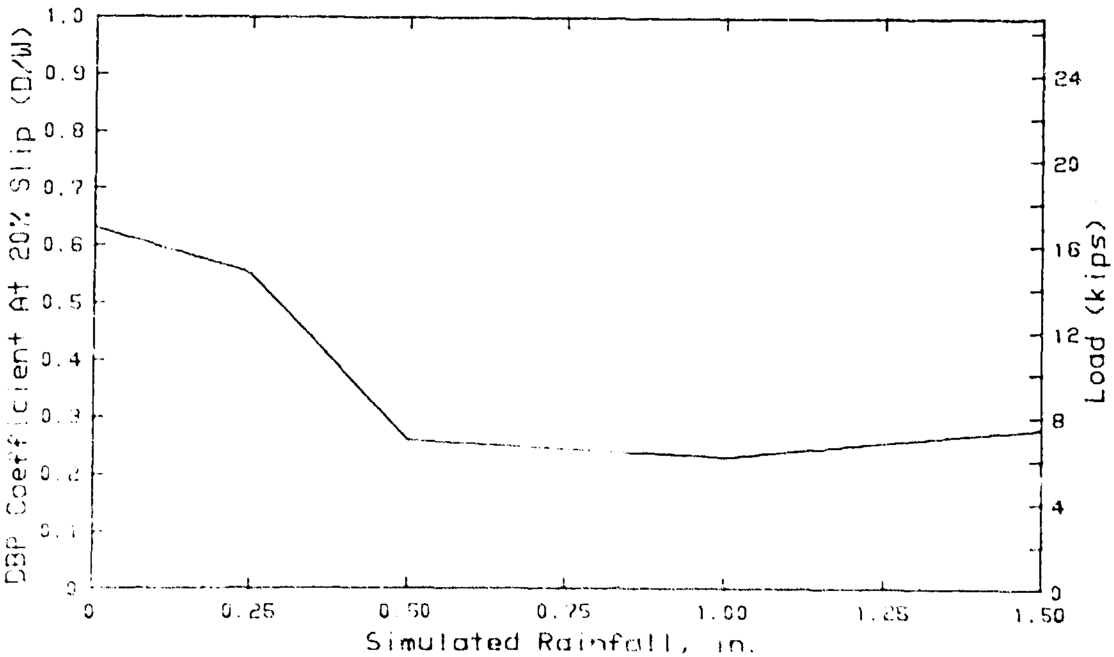
20%, Drawbar Pull Coefficient

LAV25; Duckport, La; CL Soil

Plate 2

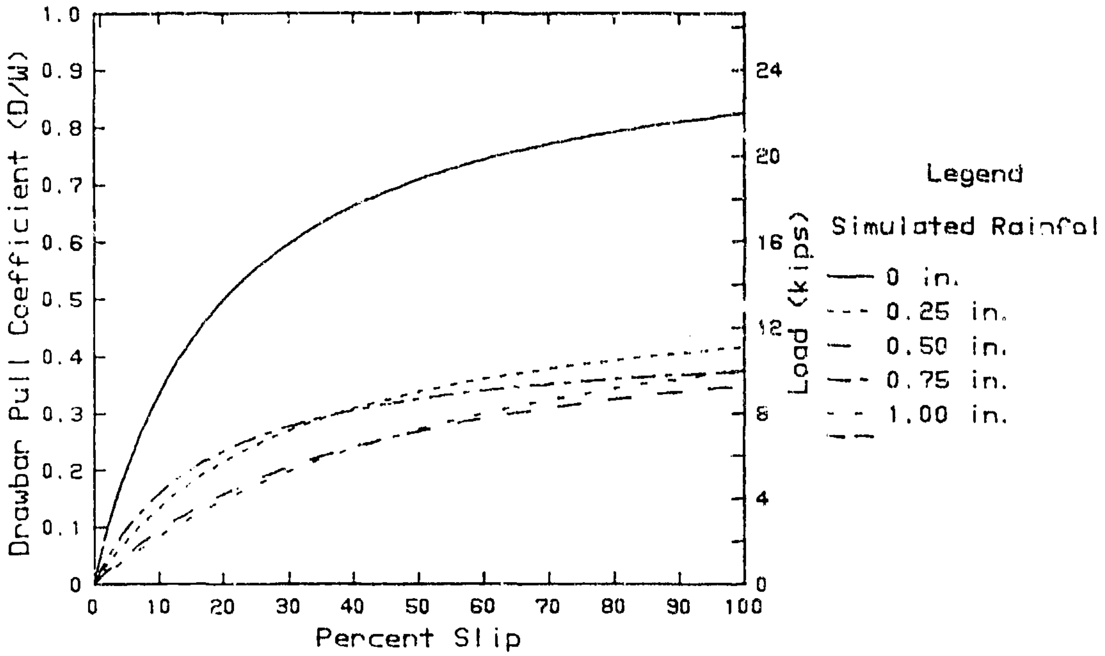


Drawbar Pull Tests

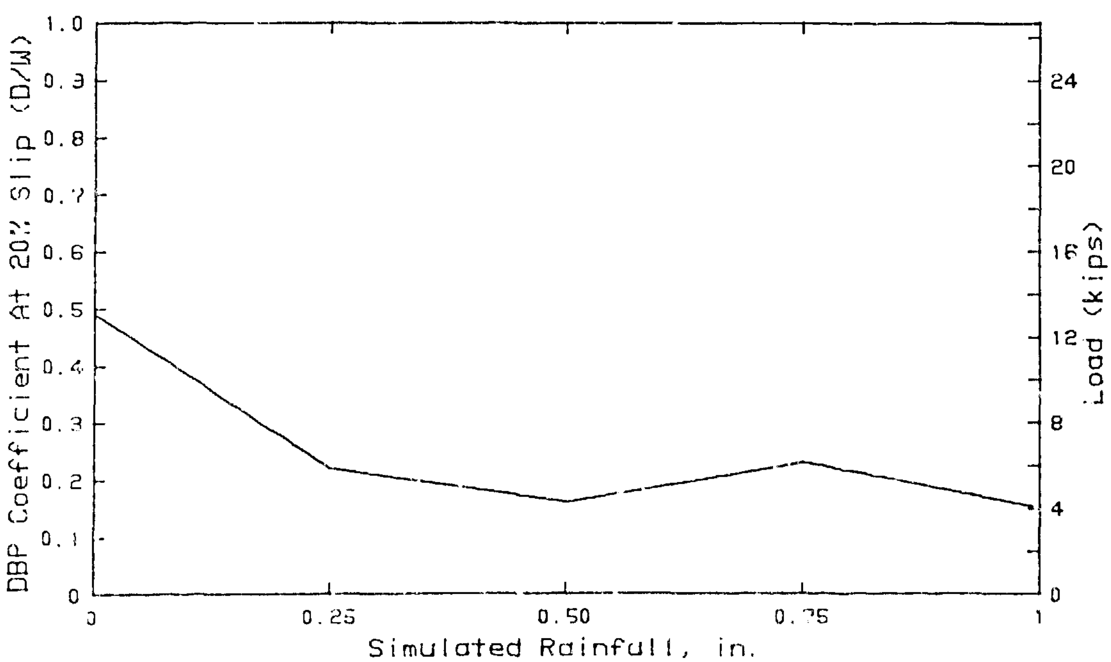


20%. Drawbar Pull Coefficient

LAV25; LeTourneau, Ms; ML Soil

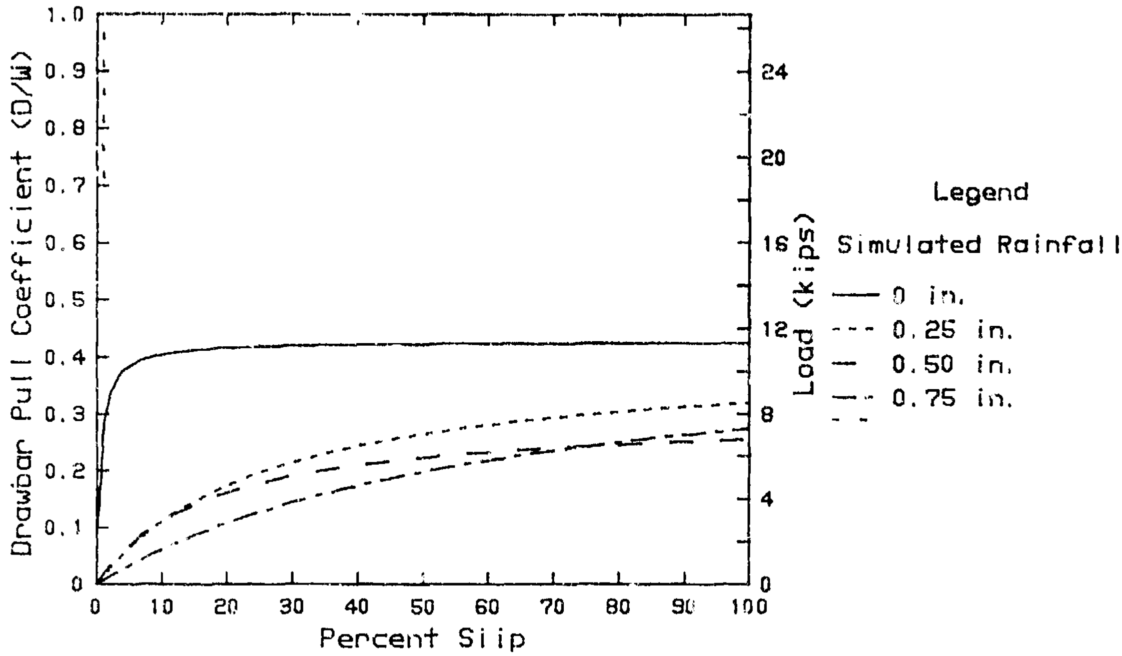


Drawbar Pull Tests

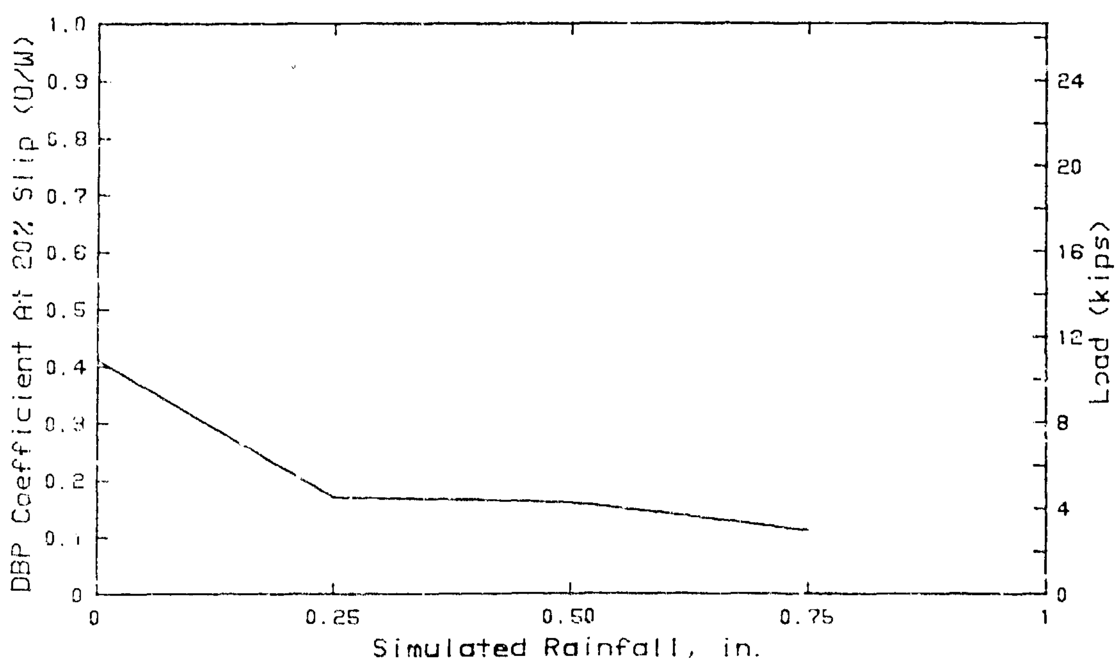


20%, Drawbar Pull Coefficient

LAV25: Fort Chaffee, Ar; SC Soil

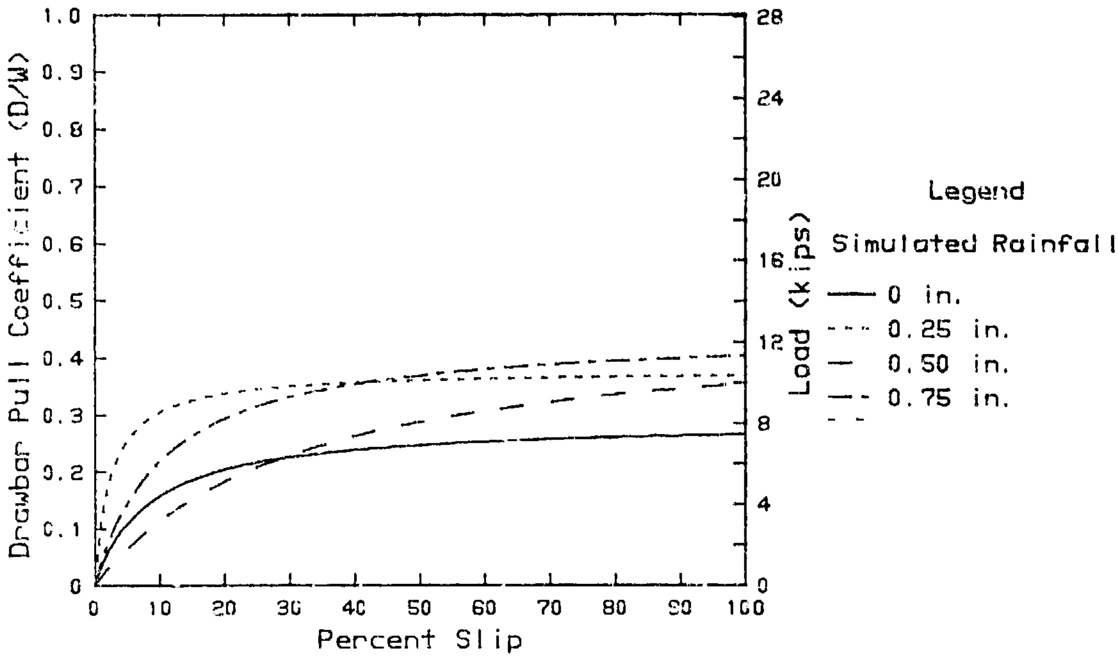


Drawbar Pull Tests

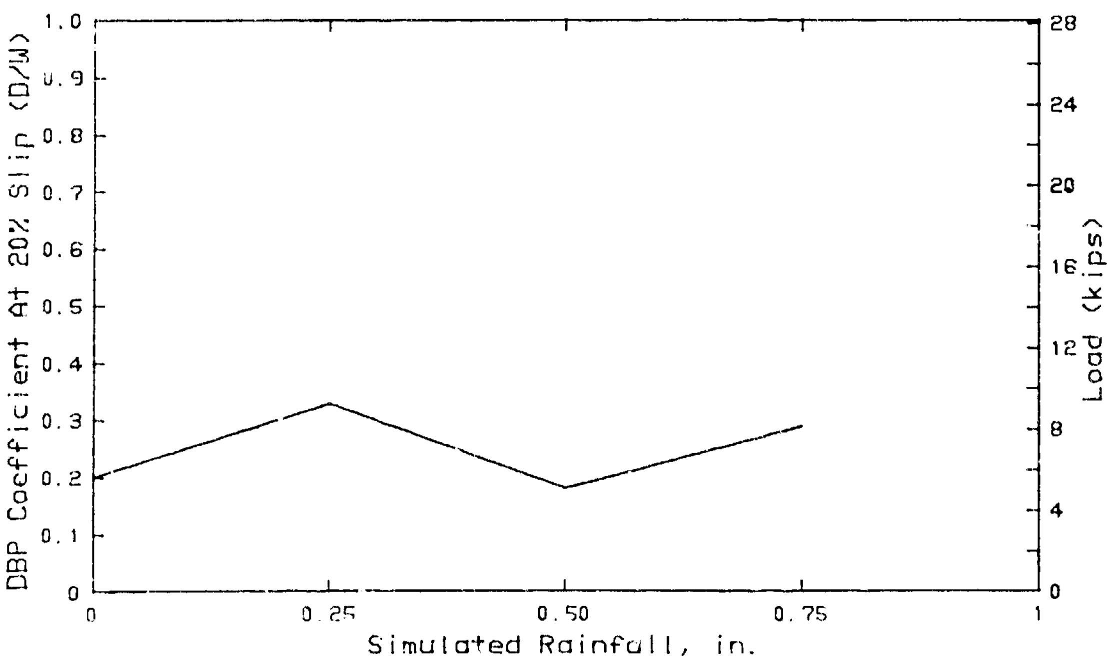


20%, Drawbar Pull Coefficient

LAV25; Fort Chaffee, Ar; SM Soil

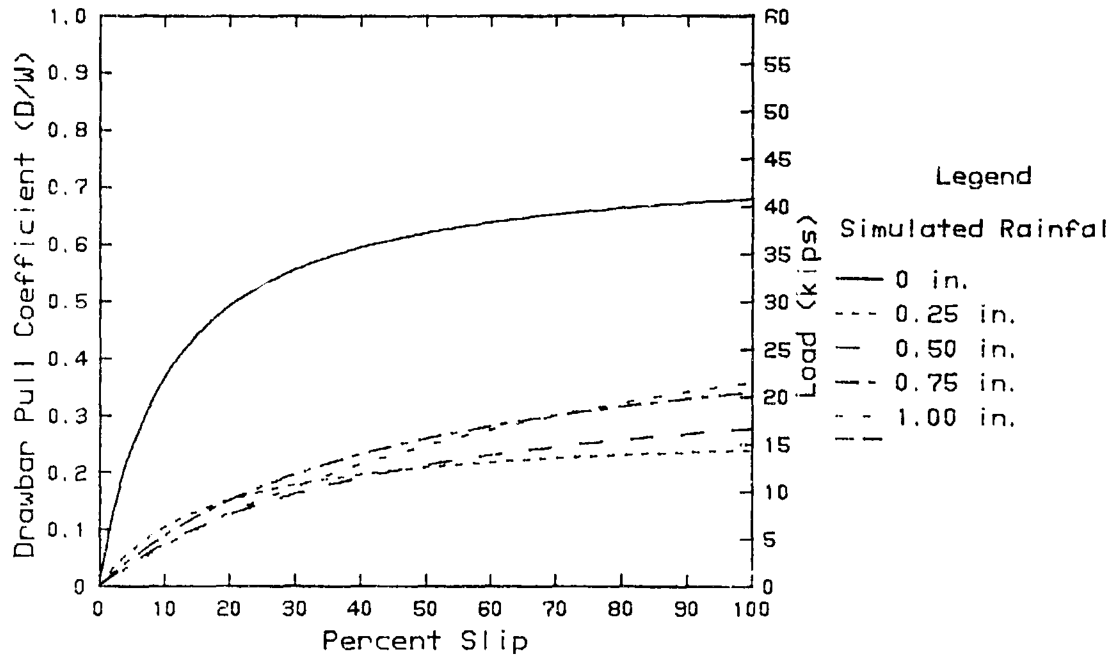


Drawbar Pull Tests

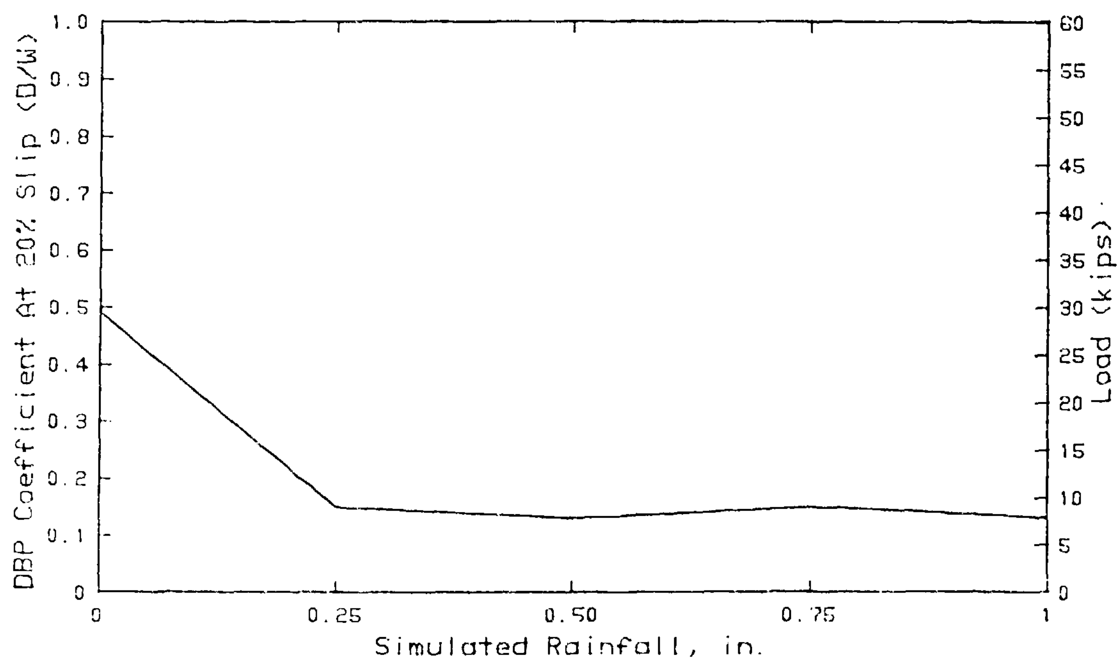


20%, Drawbar Pull Coefficient

LAV25; Duckport, La; SP Soil



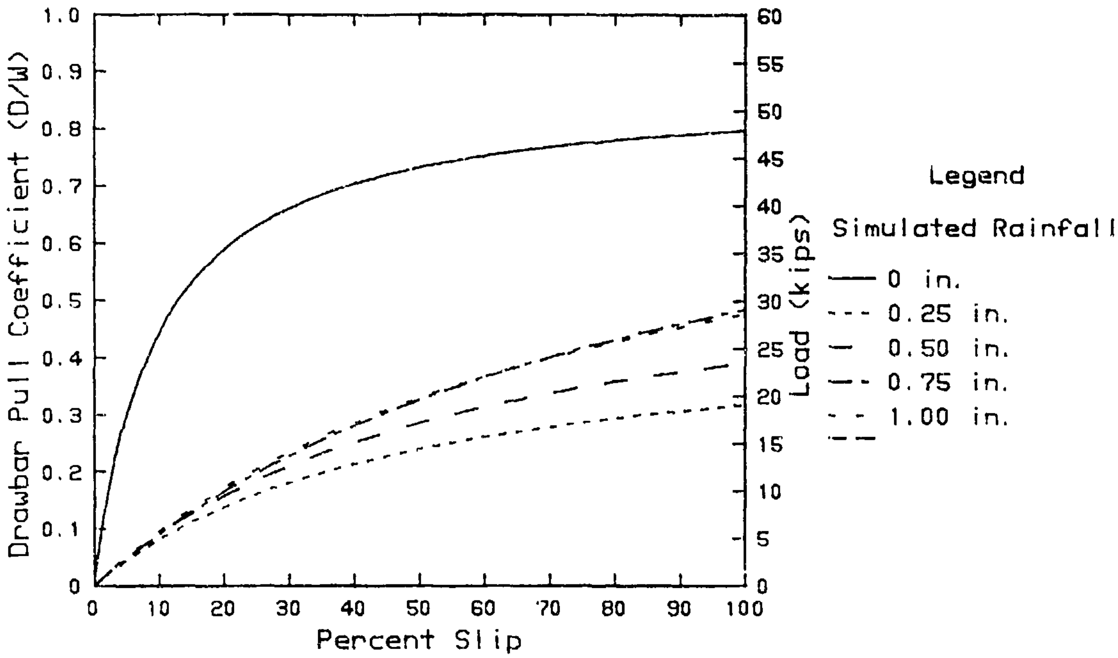
Drawbar Pull Tests



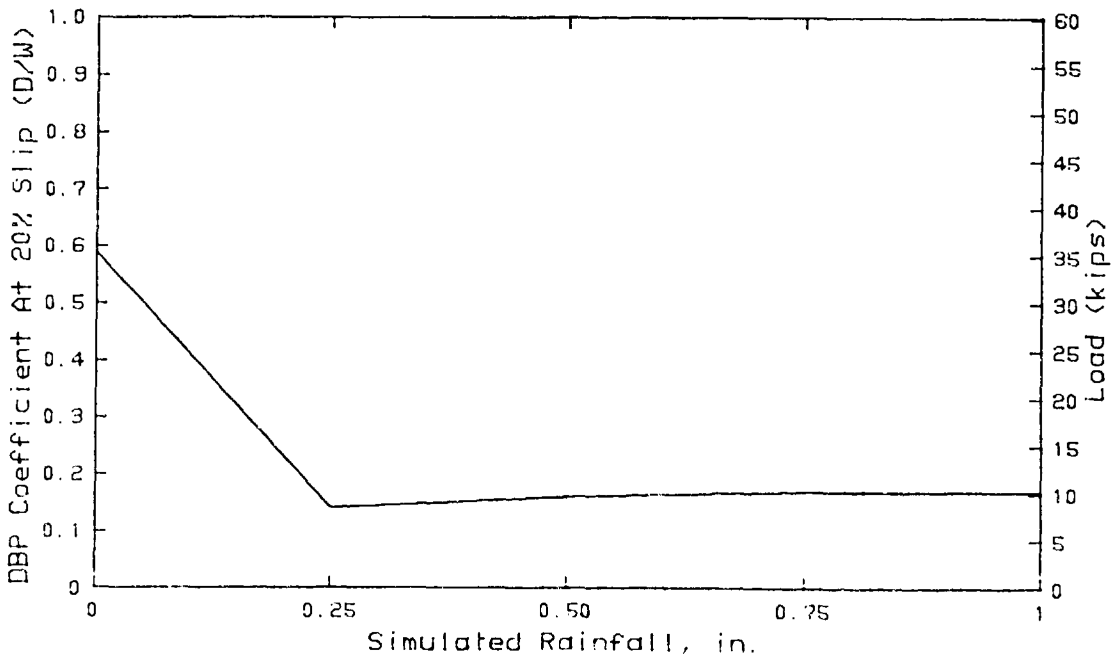
20%, Drawbar Pull Coefficient

HEMTT; Duckport, La; CH Soil

Plate 7



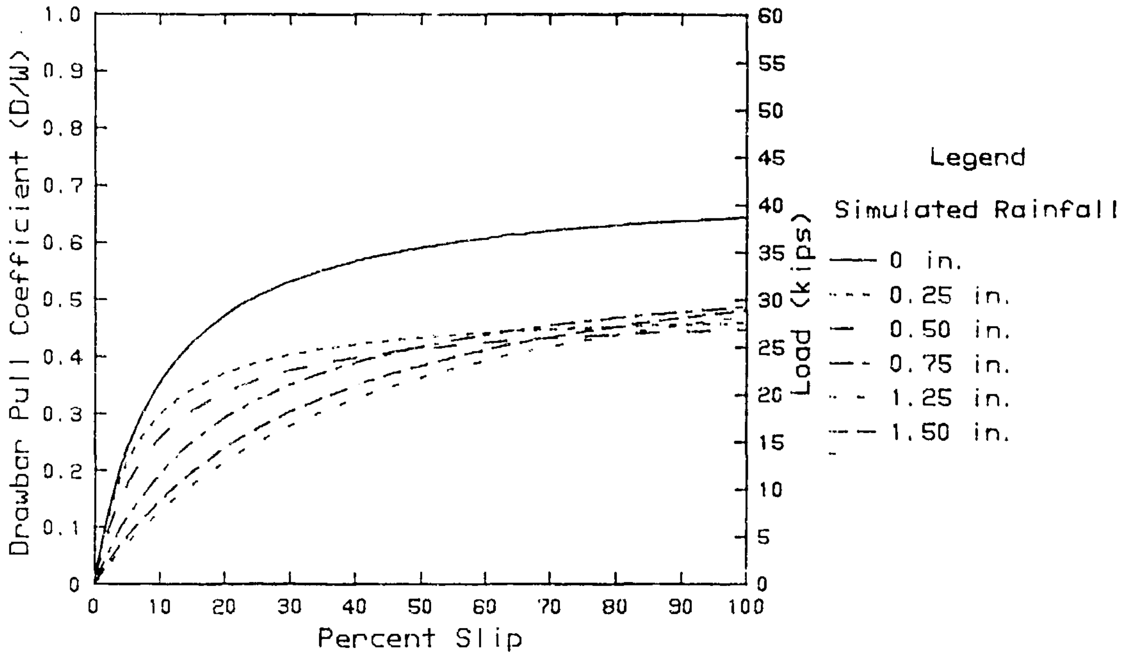
Drawbar Pull Tests



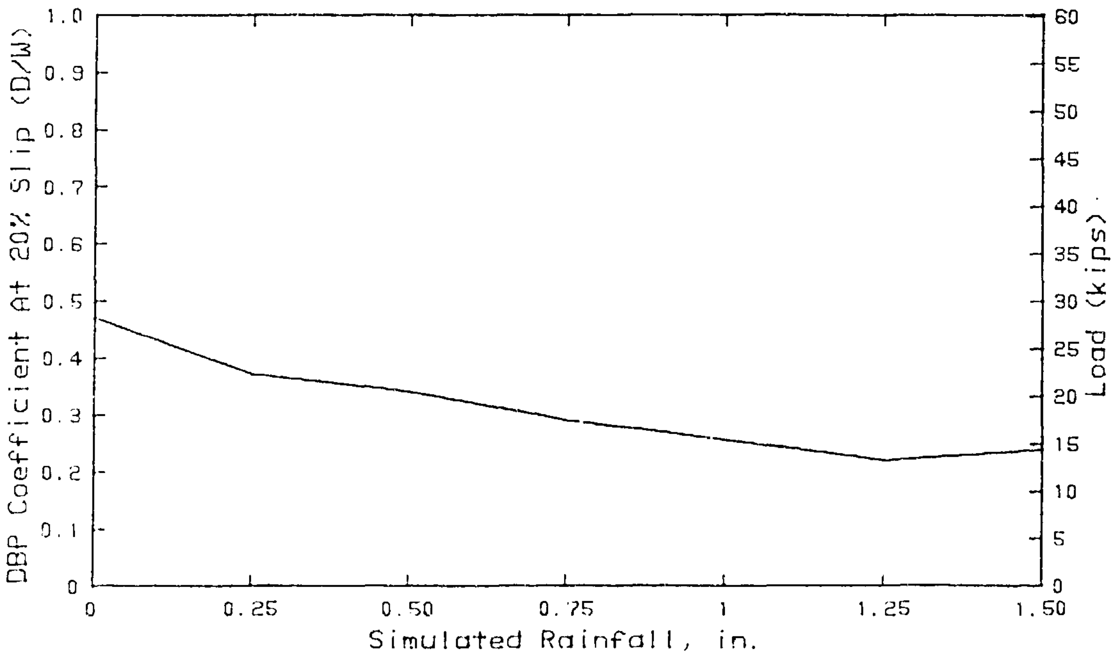
20%, Drawbar Pull Coefficient

HEMTT; Duckport, La; CL Soil

Plate 8



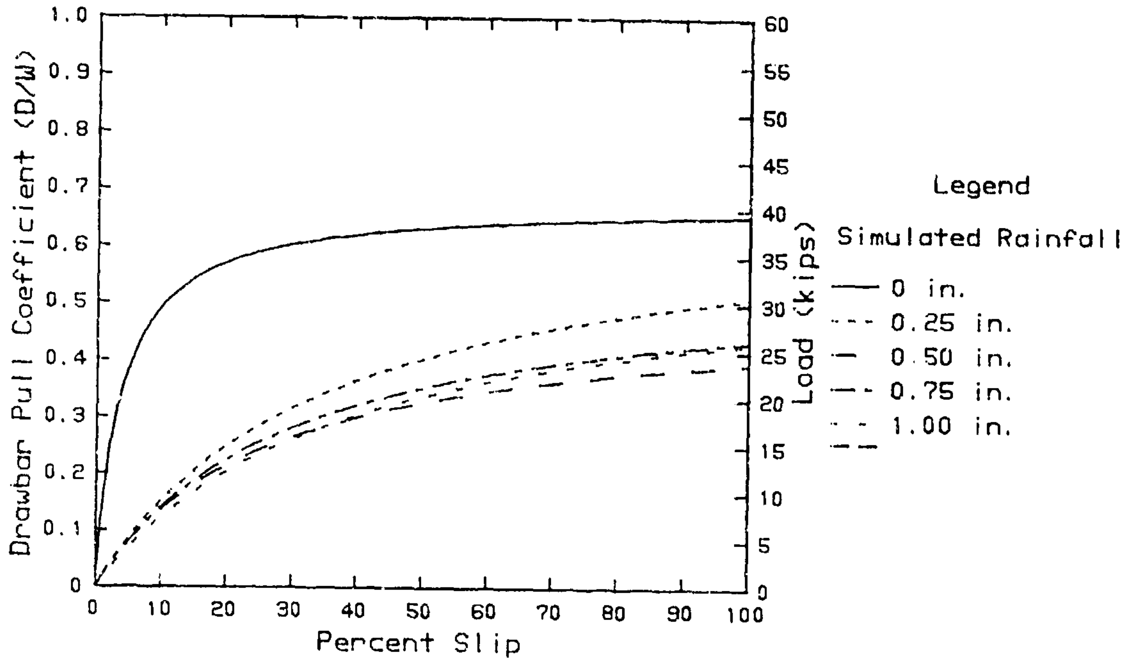
Drawbar Pull Tests



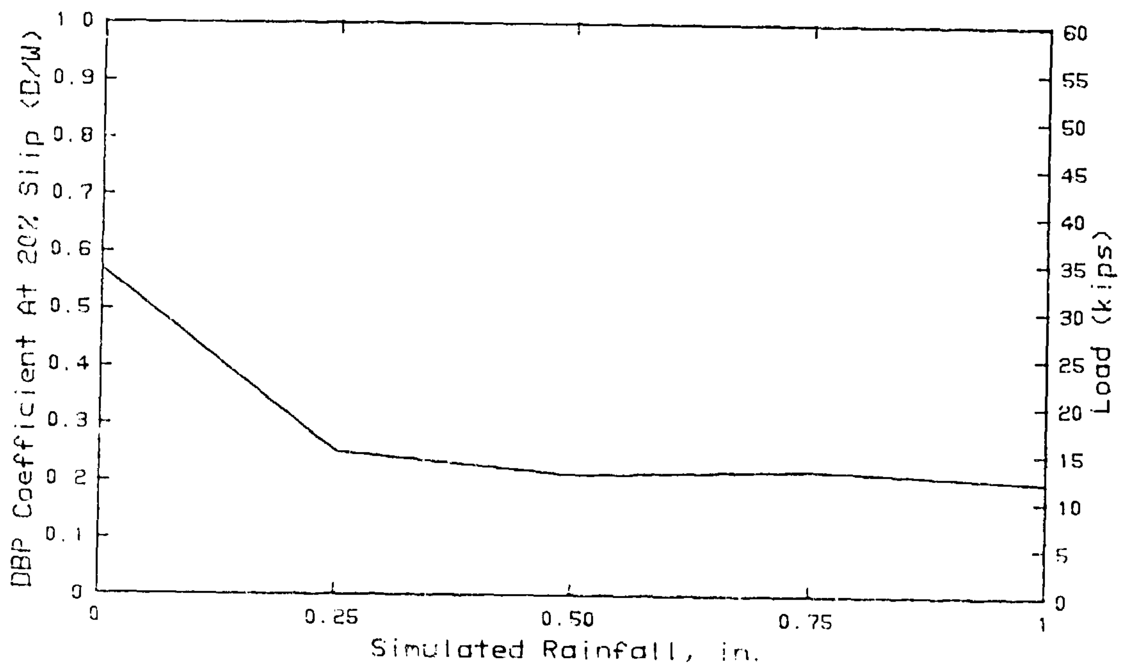
20%, Drawbar Pull Coefficient

HEMTT; LeTourneau, Ms; ML Soil

Plate 9

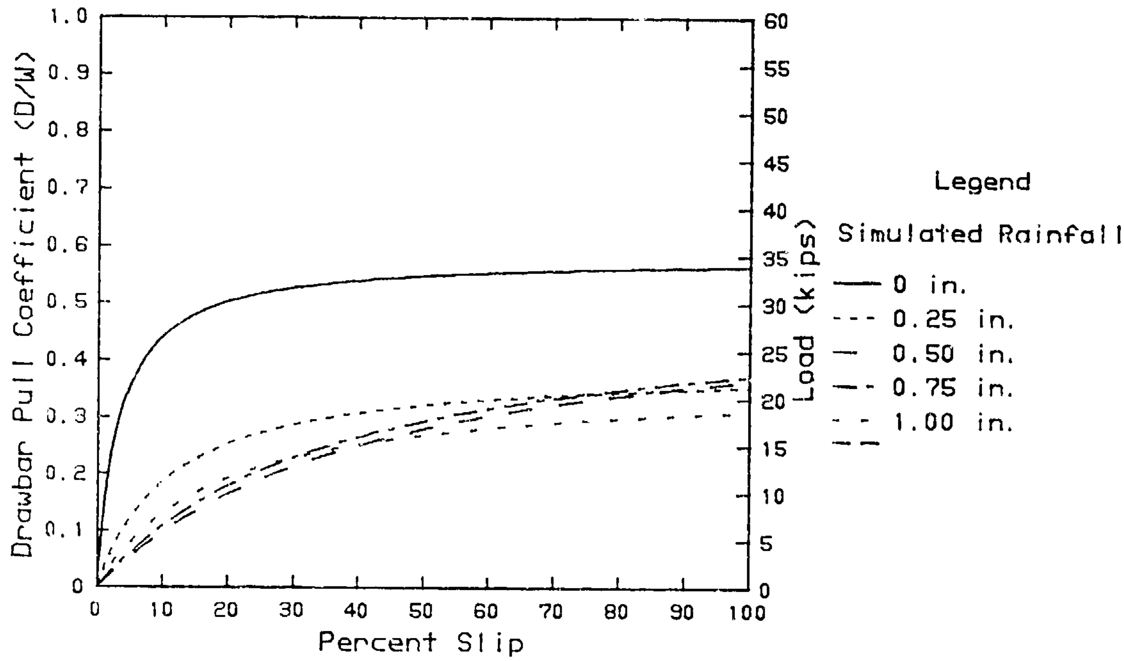


Drawbar Pull Tests

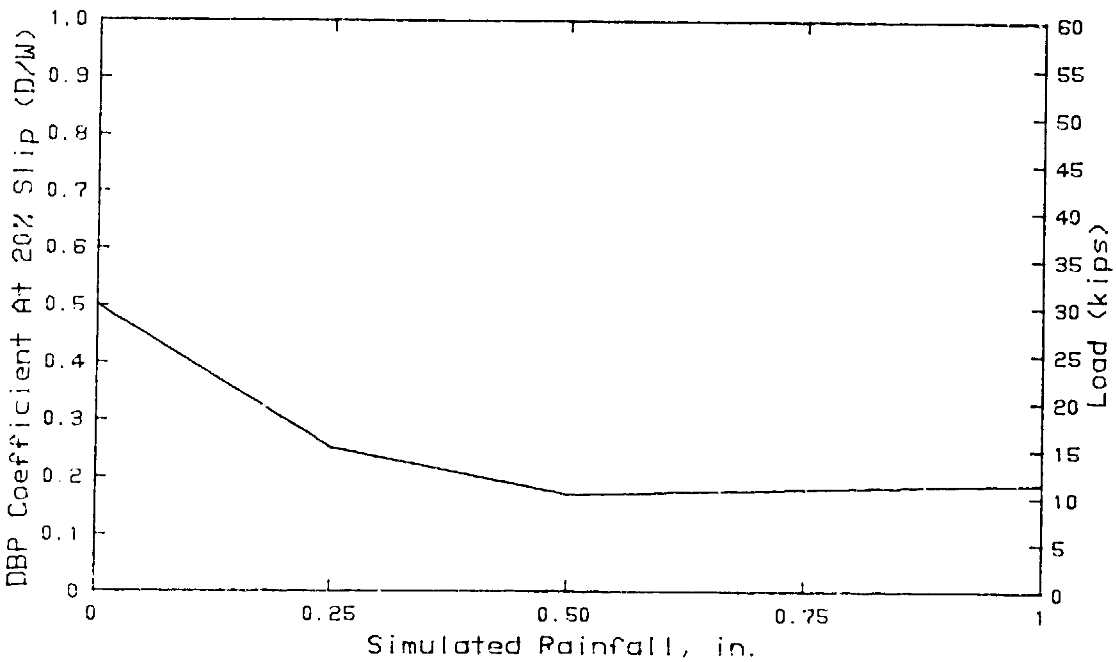


20%, Drawbar Pull Coefficient

HEMTT; Fort Chaffee, Ar; SC Soil

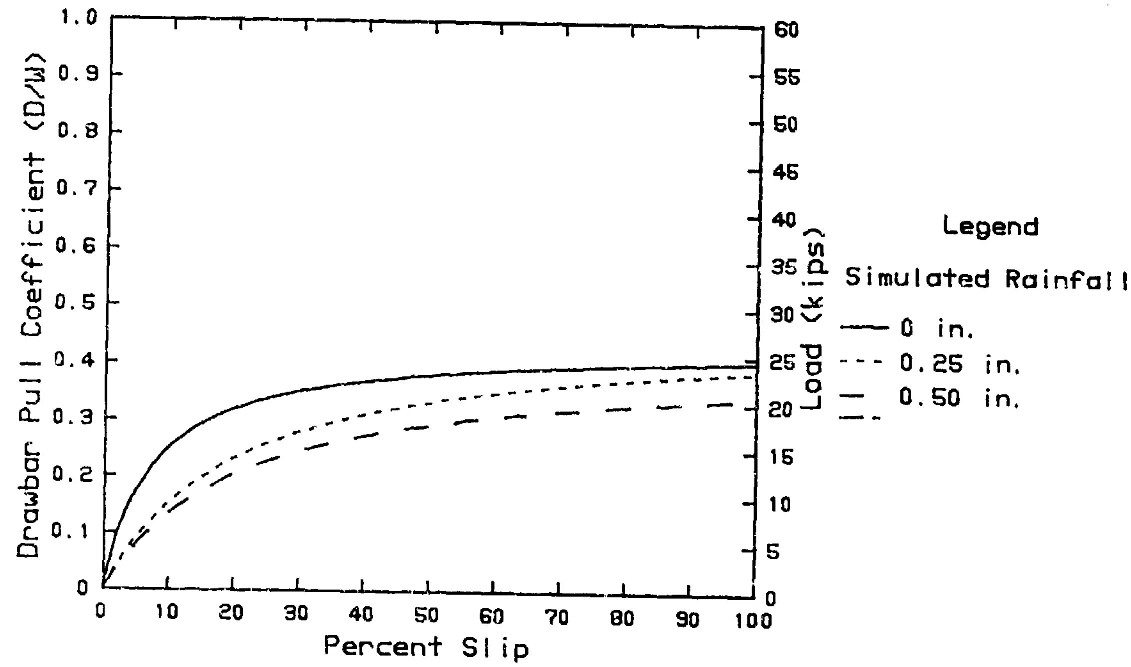


Drawbar Pull Tests

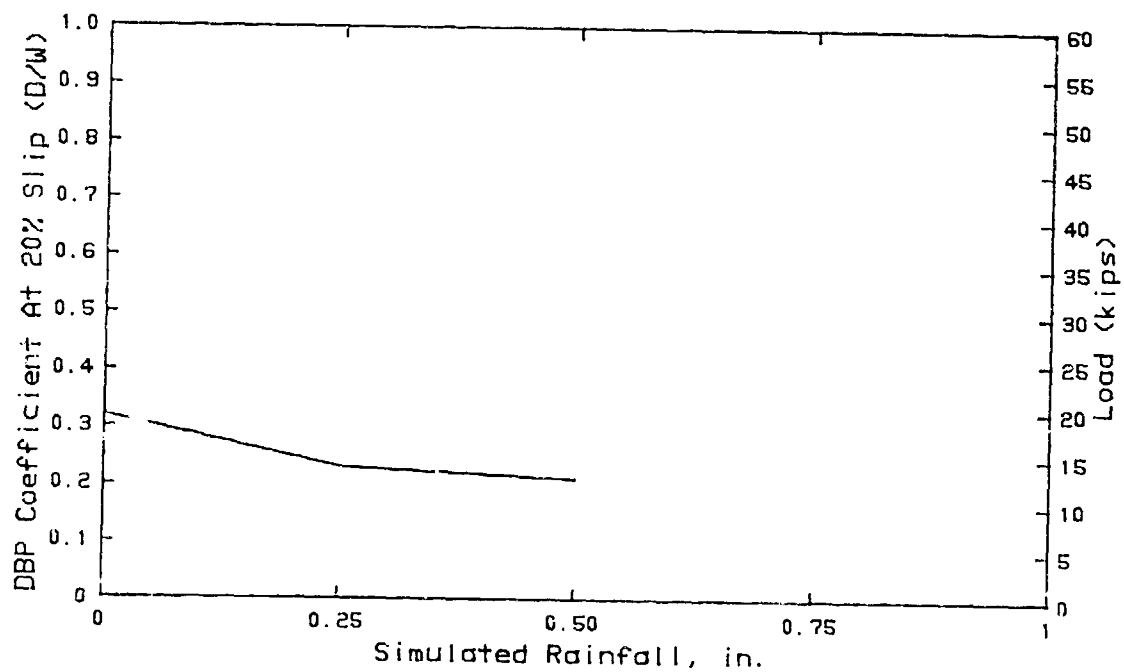


20%, Drawbar Pull Coefficient

HEMTT; Fort Chaffee, Ar, SM Soil



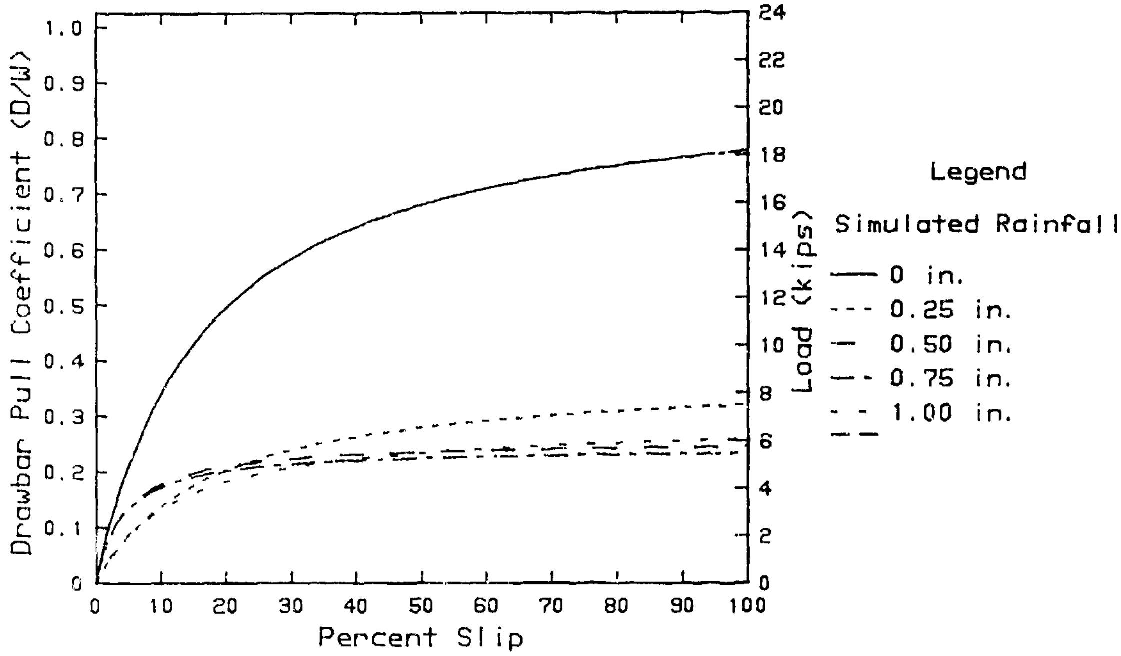
Drawbar Pull Tests



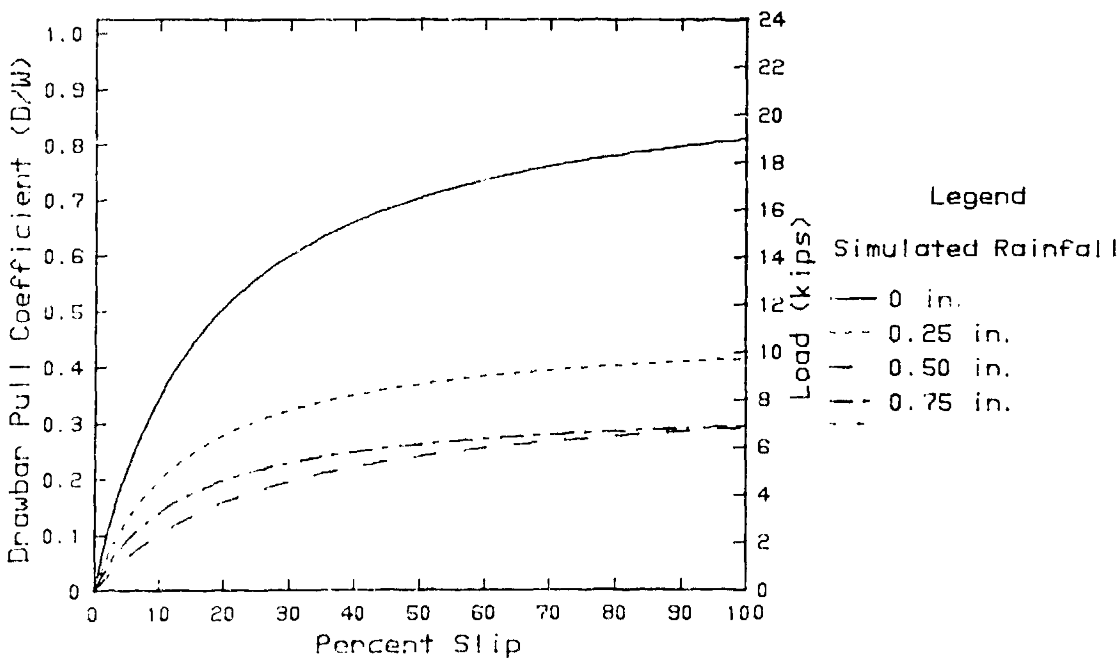
20%, Drawbar Pull Coefficient

HEMTT; Duckport, La; SP Soil

Plate 12

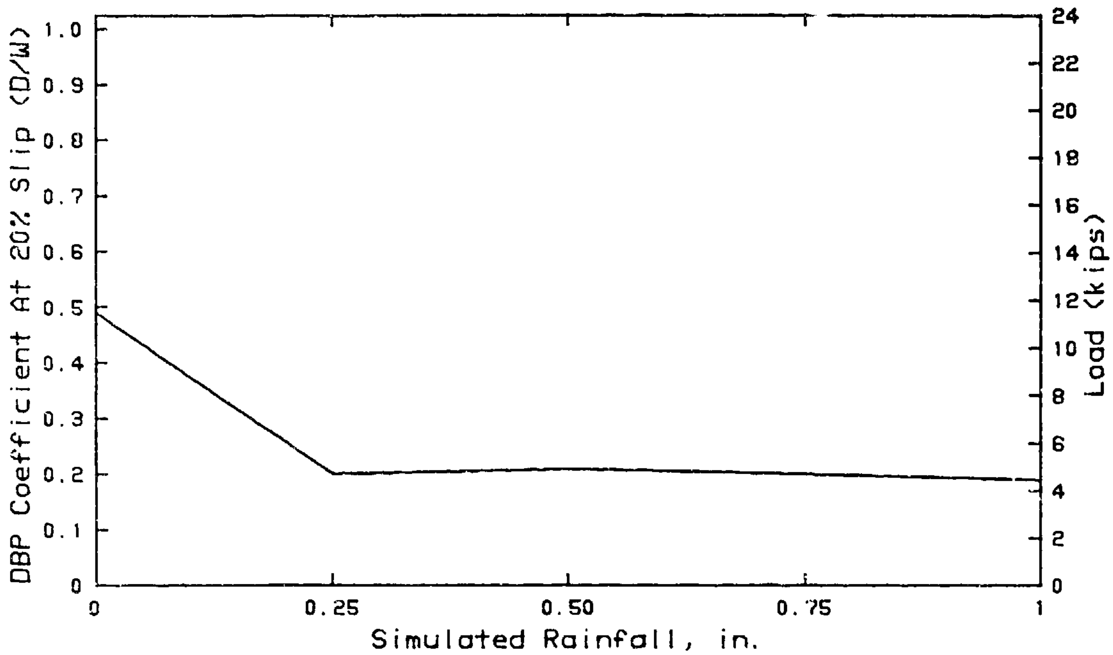


Drawbar Pull Tests; CH Soil

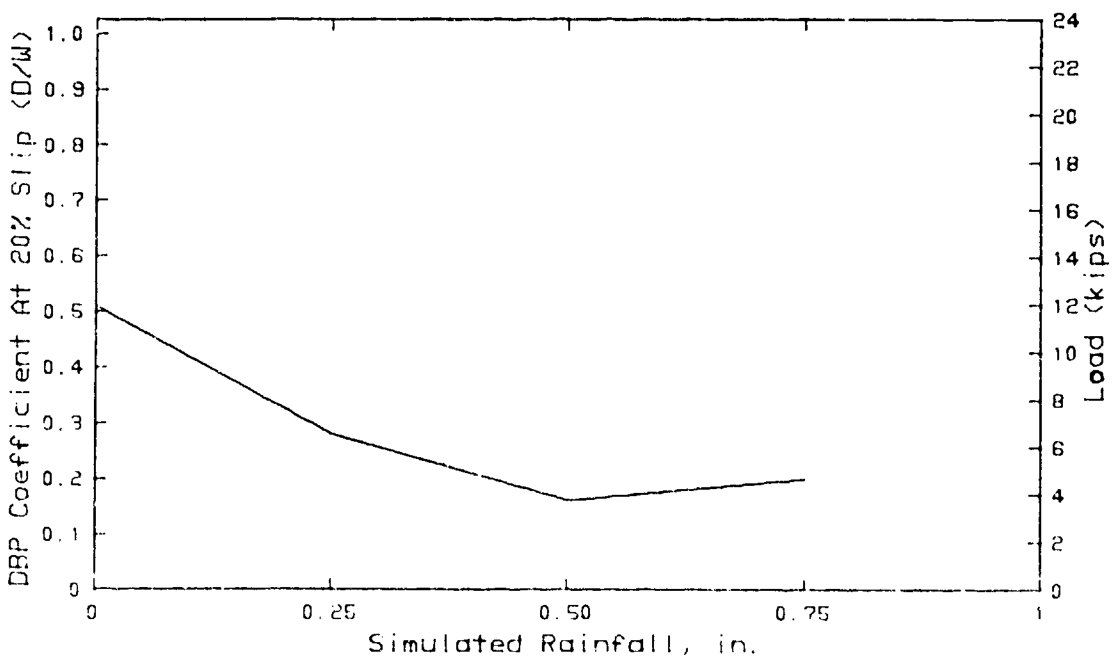


Drawbar Pull Tests; CL Soil

M113A1, Duckport, La.

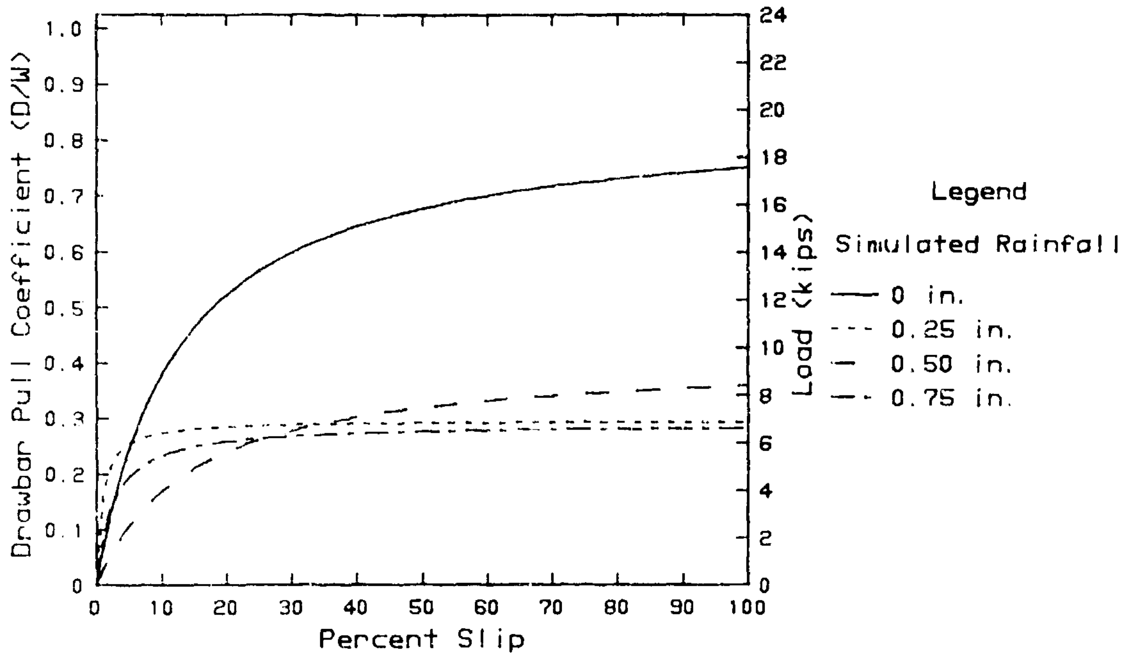


20%, Drawbar Pull Coefficient; CH Soil

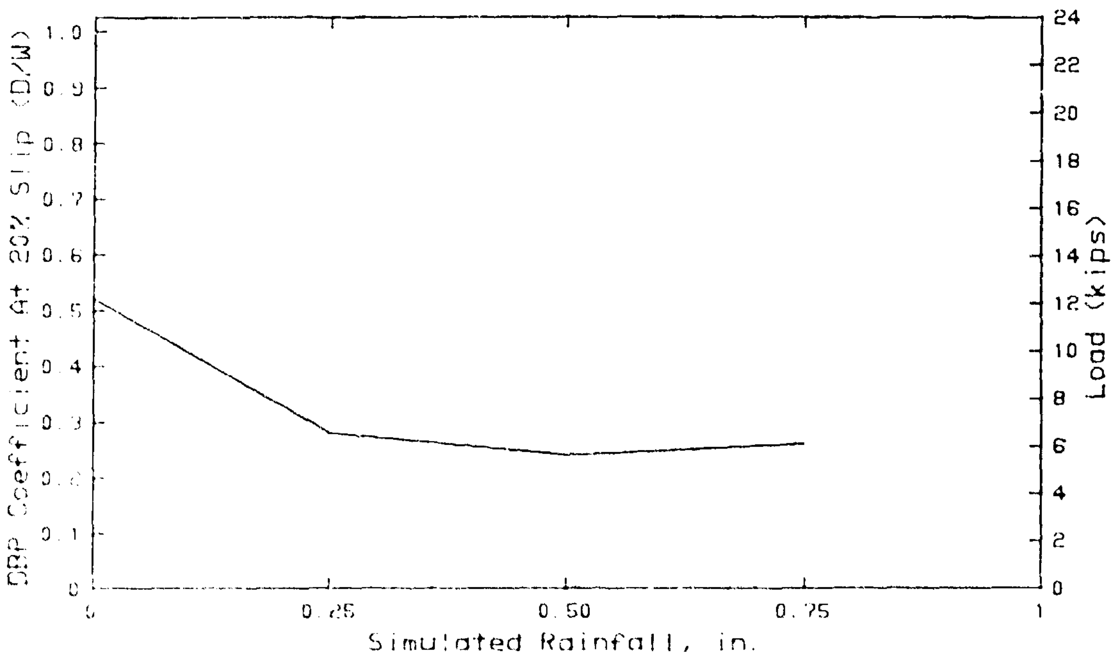


20%, Drawbar Pull Coefficient; CL Soil

M113A1, Duckport, La.

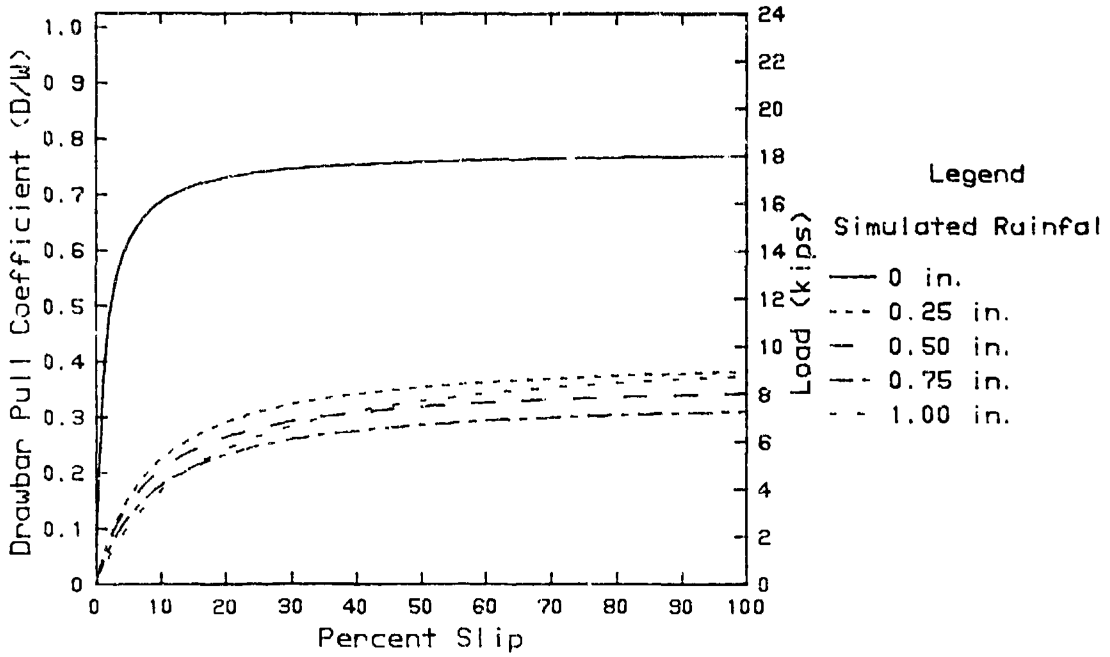


Drawbar Pull Tests

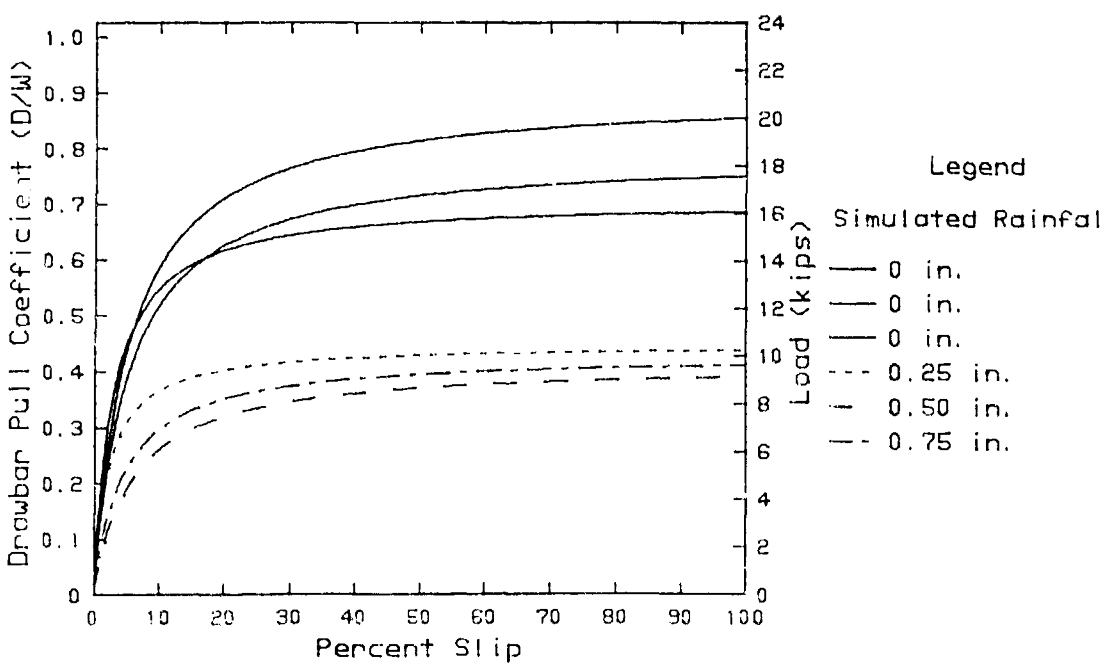


20%, Drawbar Pull Coefficient

M113A1, LeTourneau, Ms.; ML Soil

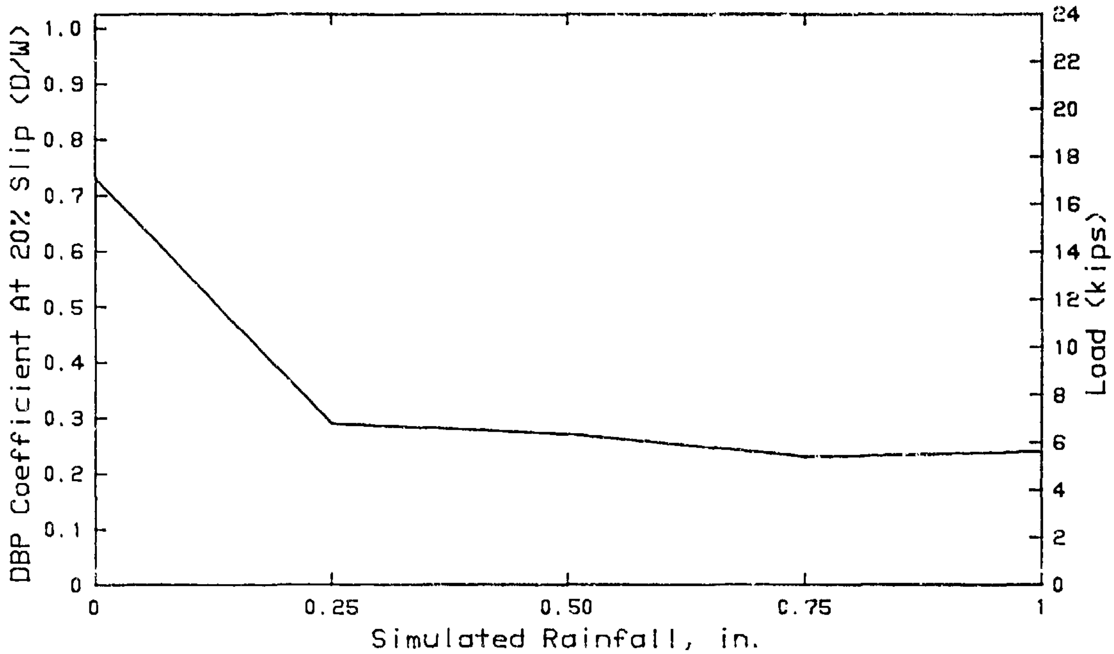


Drawbar Pull Tests; SC Soil

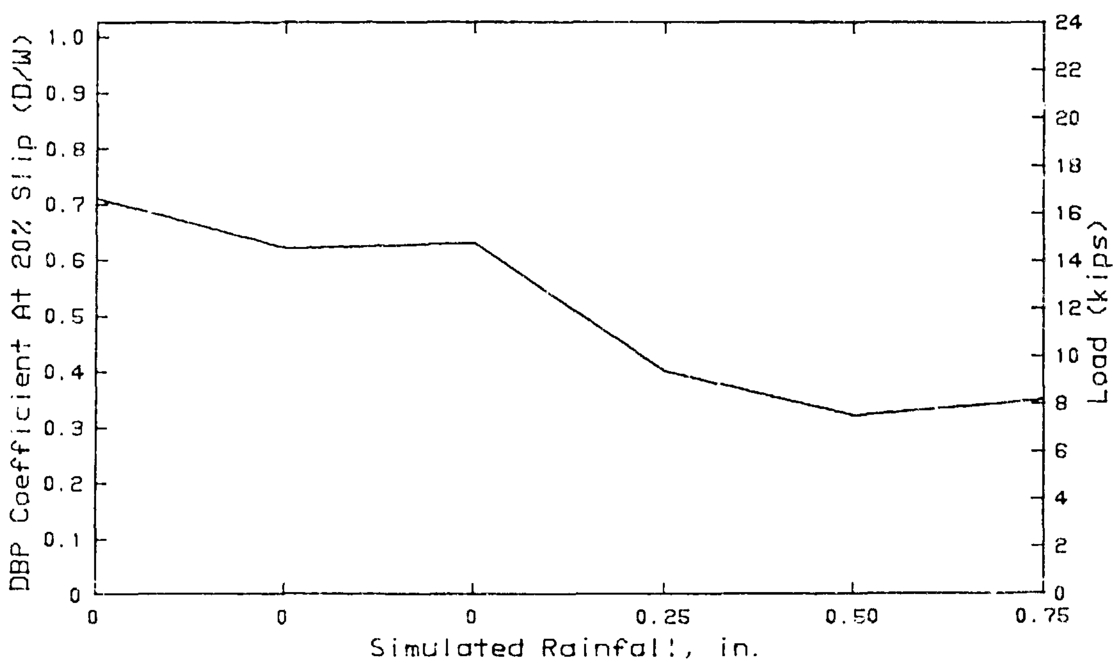


Drawbar Pull Tests; SM Soil

M113A1, Fort Chaffee, Ar.

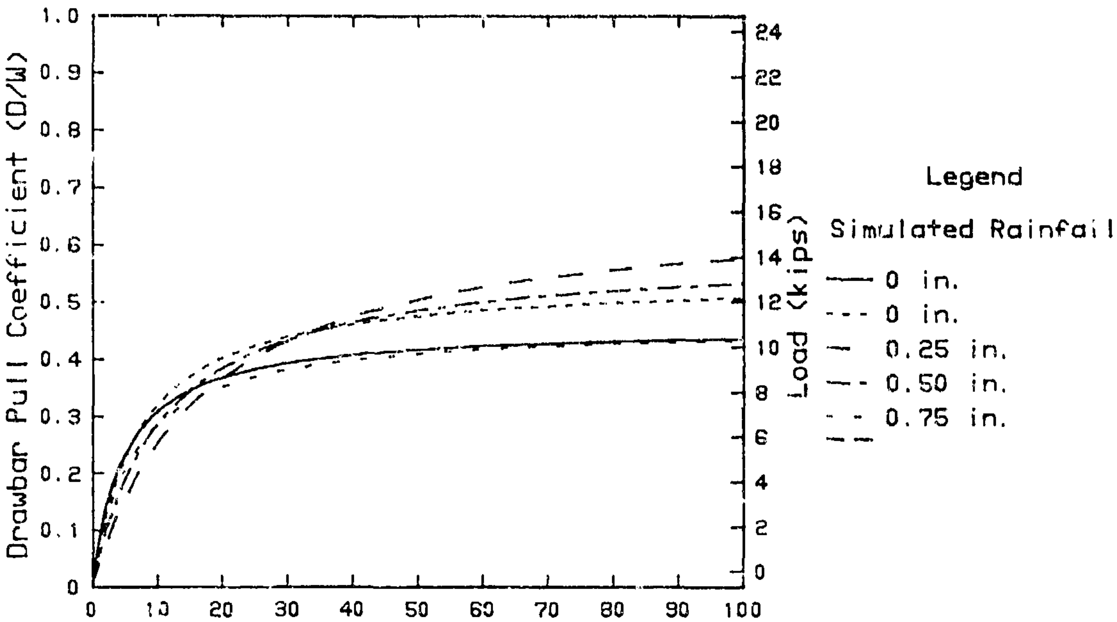


20%, Drawbar Pull Coefficient; SC Soil

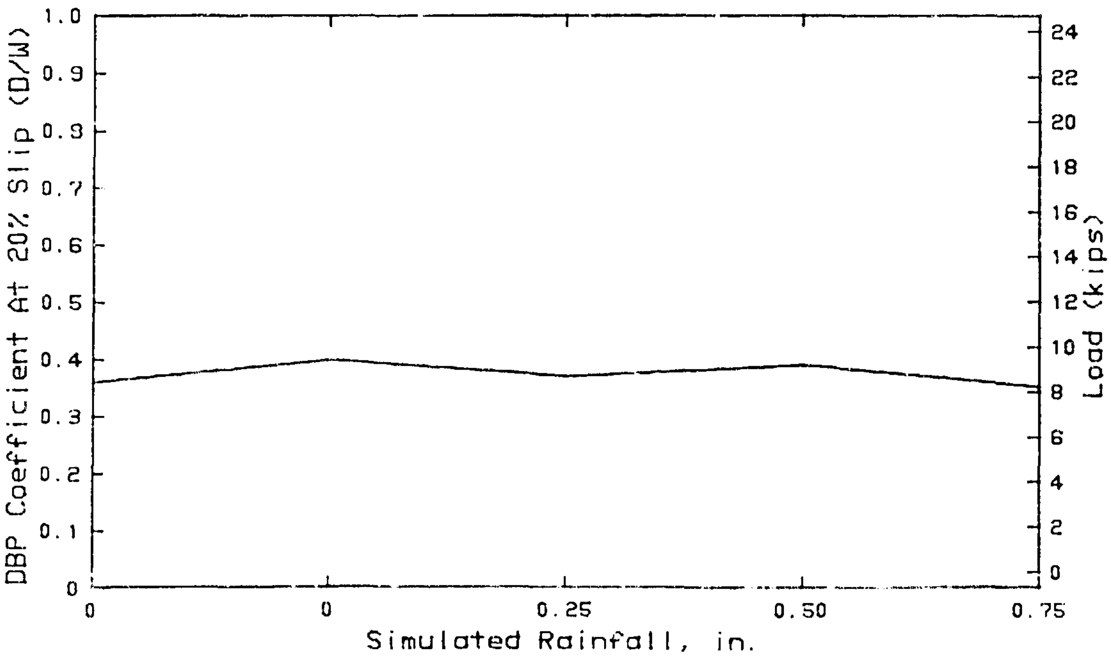


20%, Drawbar Pull Coefficient; SM Soil

M113A1, Duckport, La.



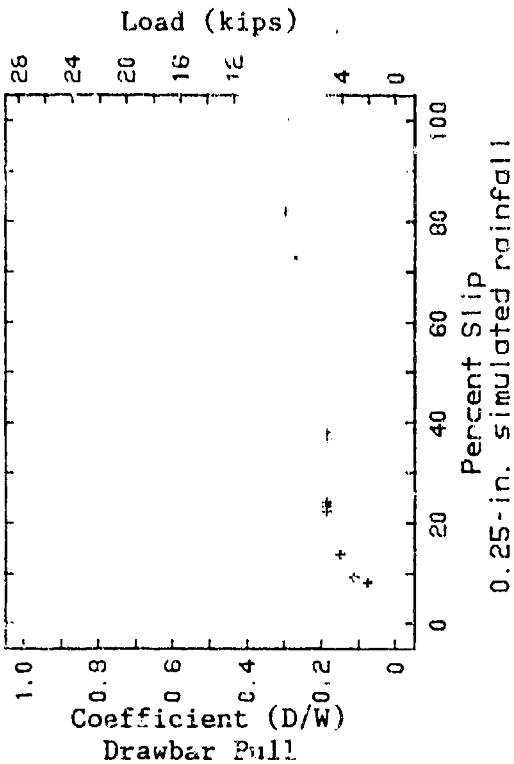
Drawbar Pull Tests

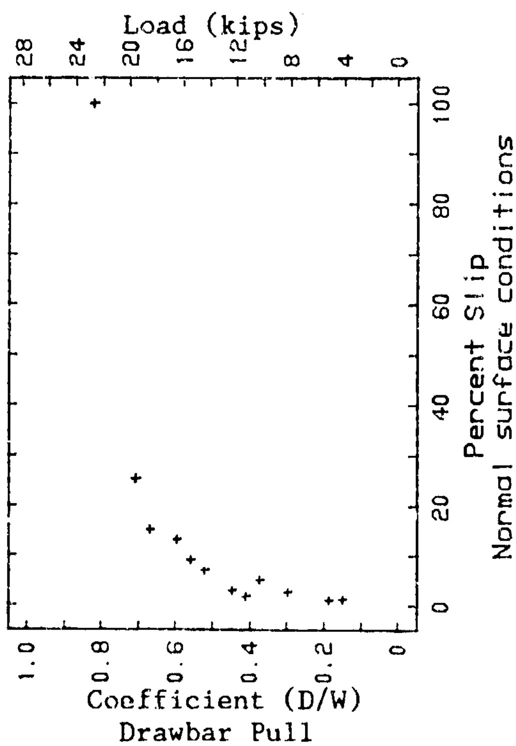


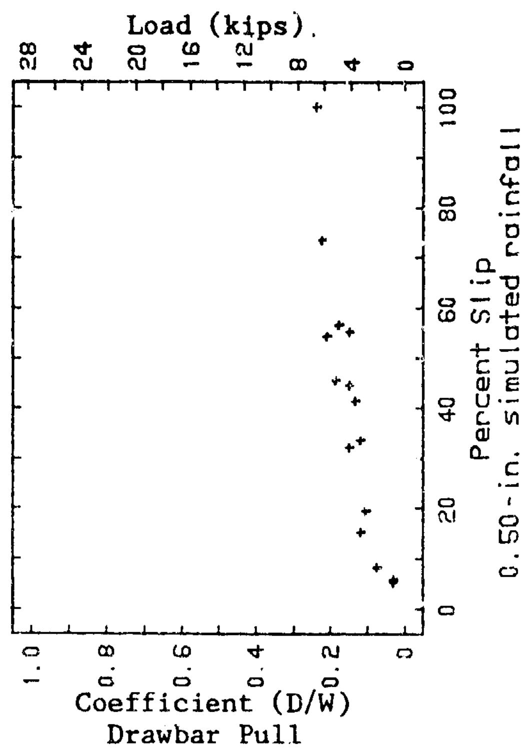
20%, Drawbar Pull Coefficient

M113A1, Duckport, La., SP Soil

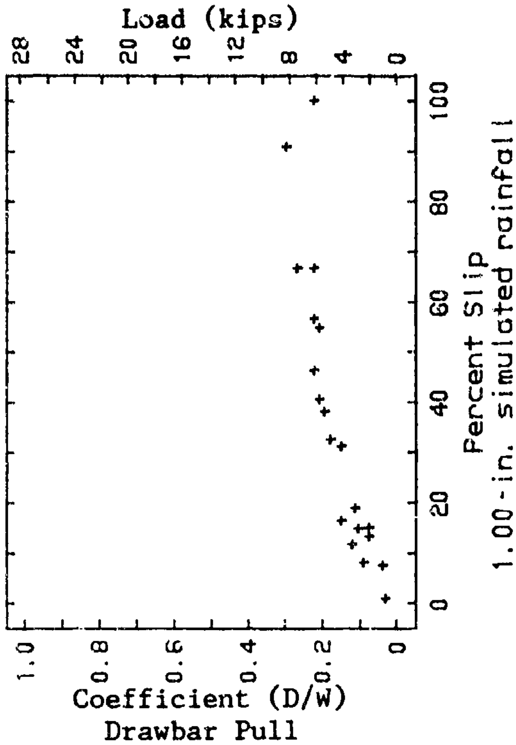
Plate 18

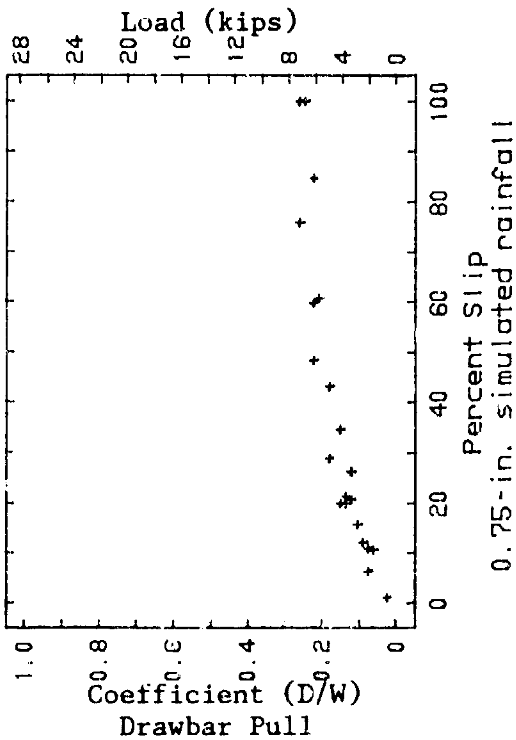




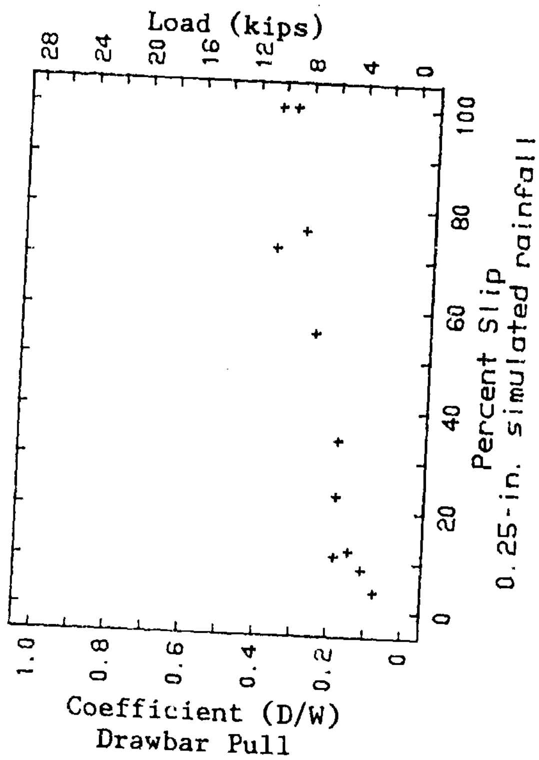


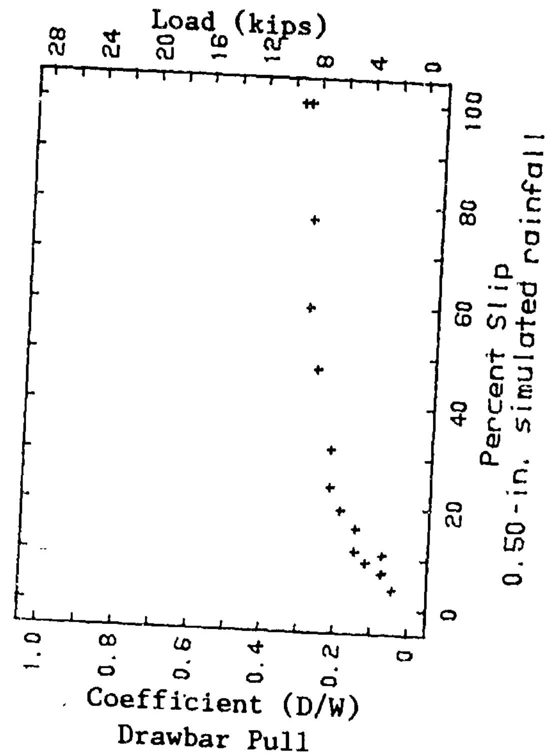
LAV25; Duckport, La.; CH Soil

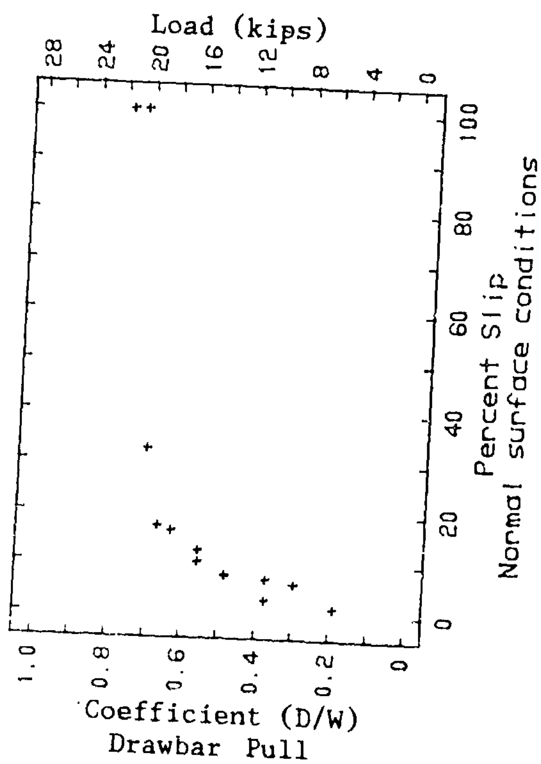




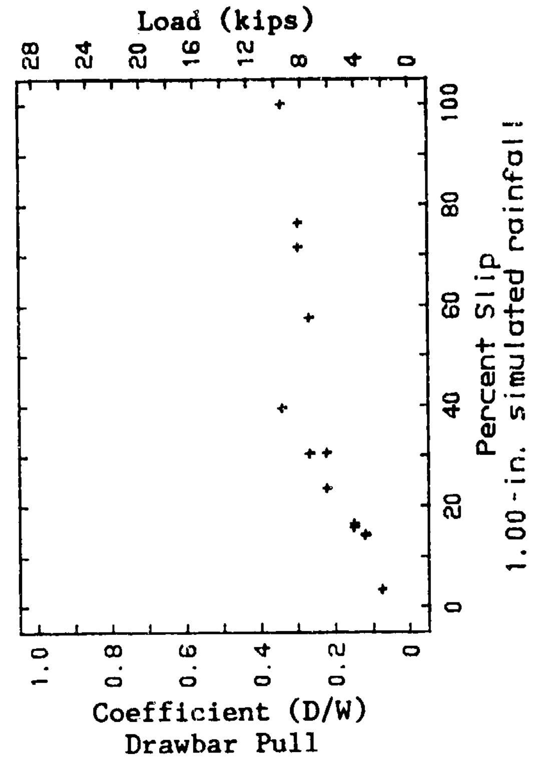
LAV25; Duckport, La.; CH Soil

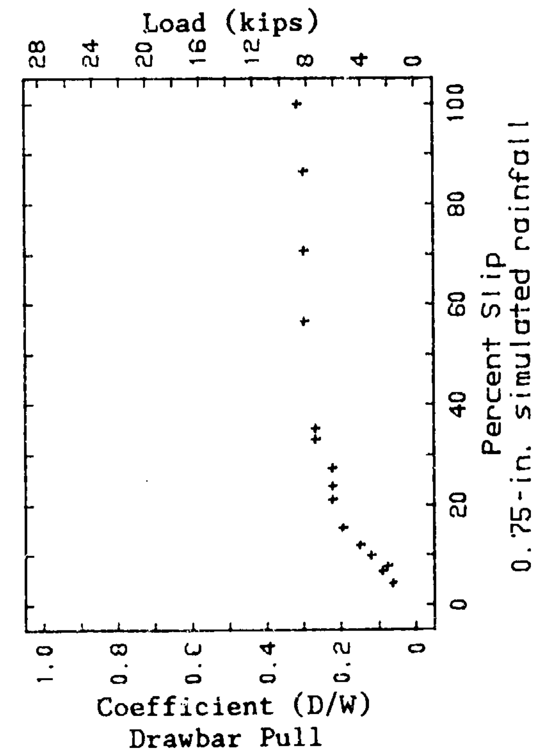




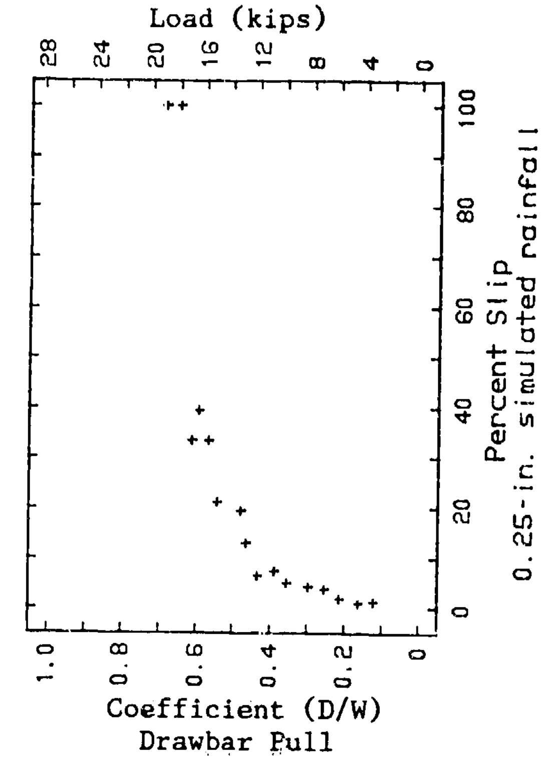


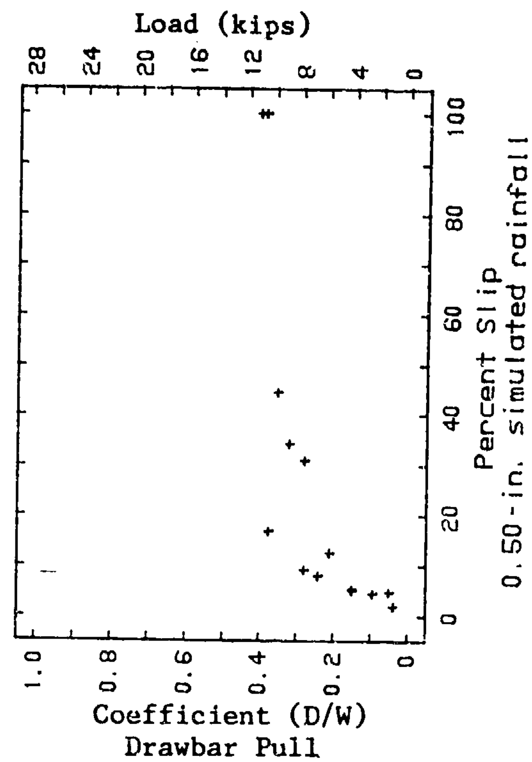
LAV25; Duckport, La.; CL Soil

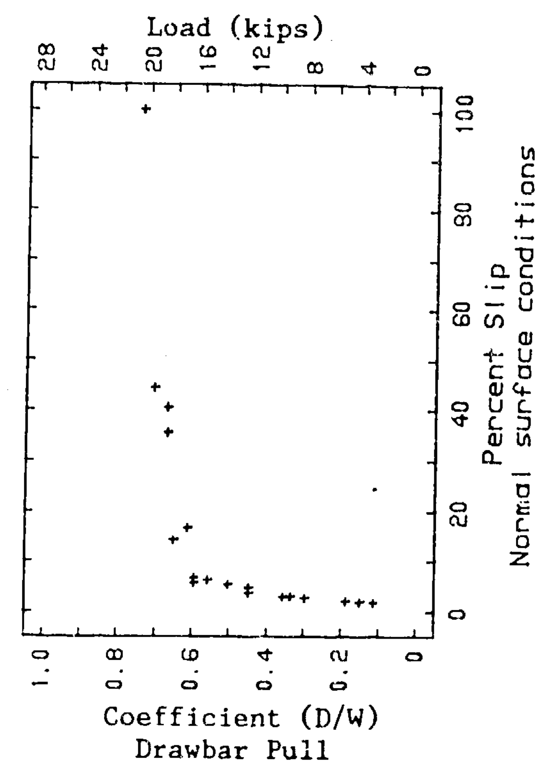




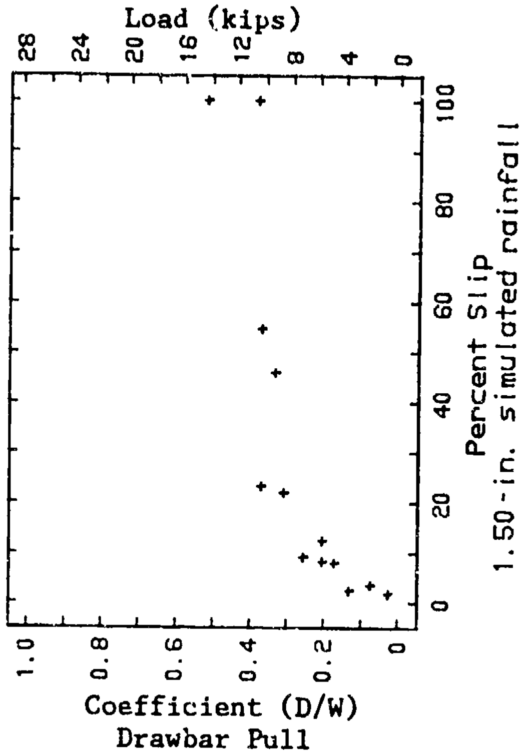
LAV25; Duckport, La.; CL Soil

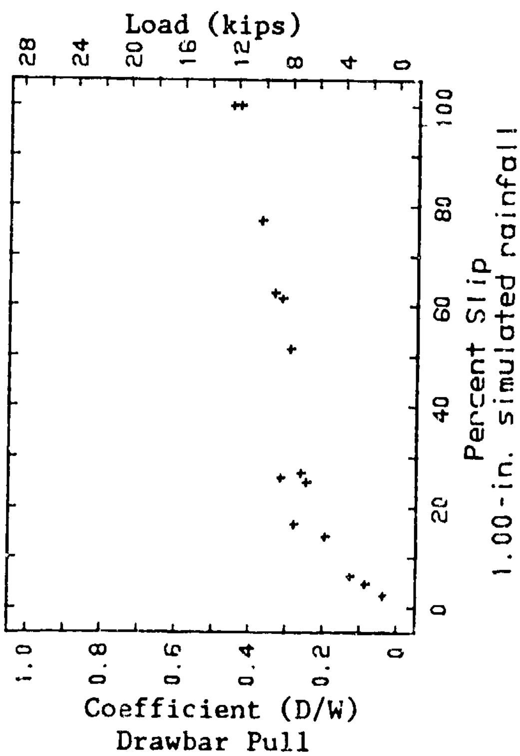




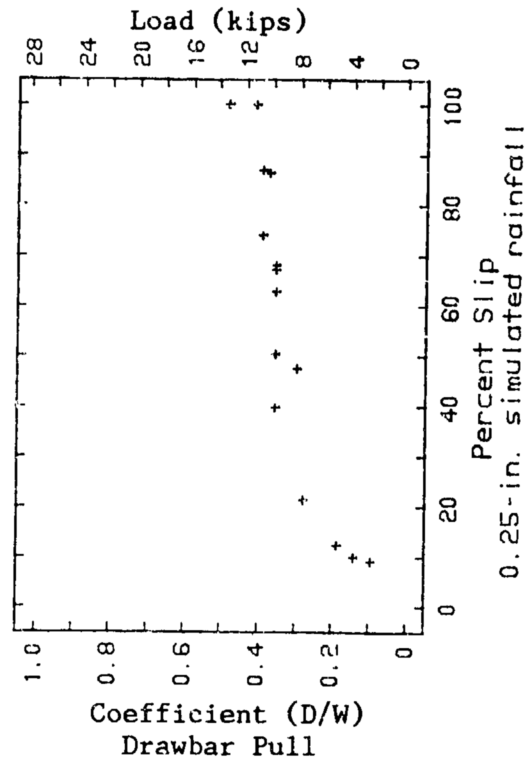


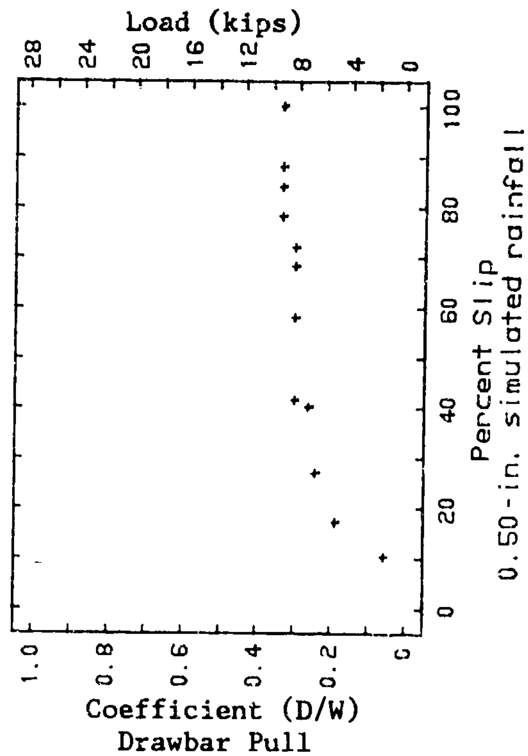
LAV25; LeTourneau, Miss.; ML Soil

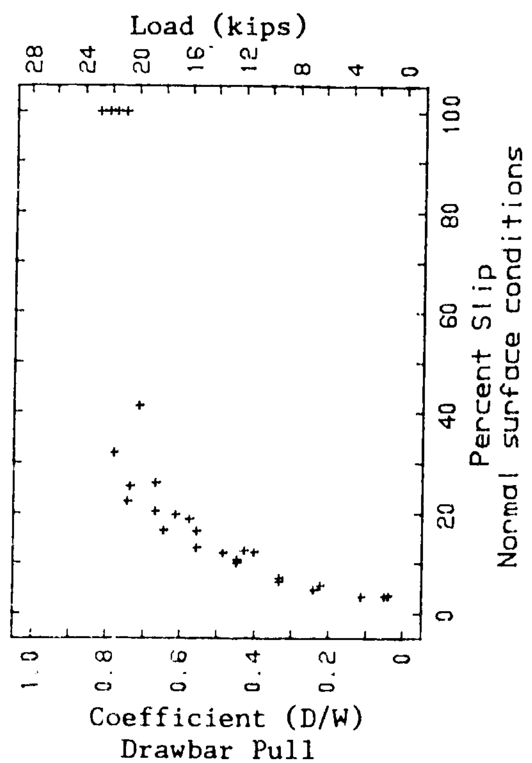




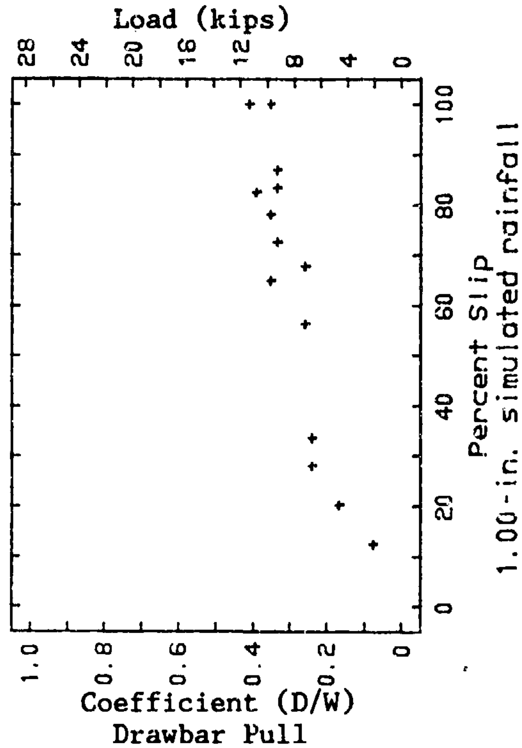
LAV25; LeTourneau, Miss.; ML Soil

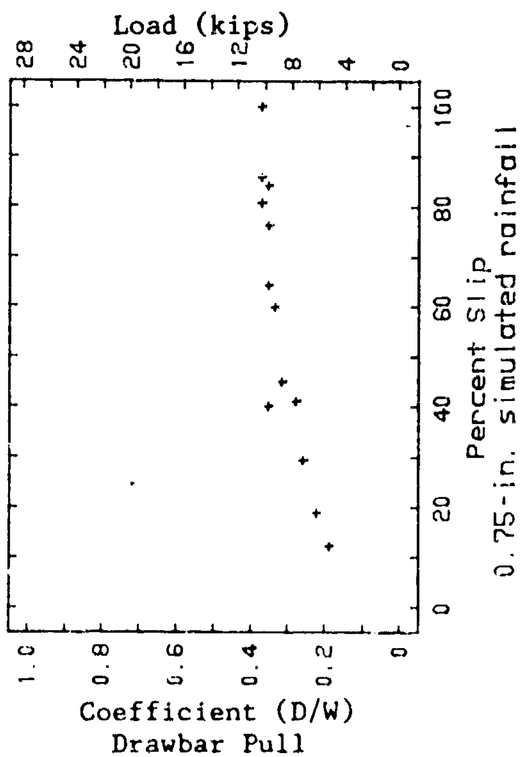




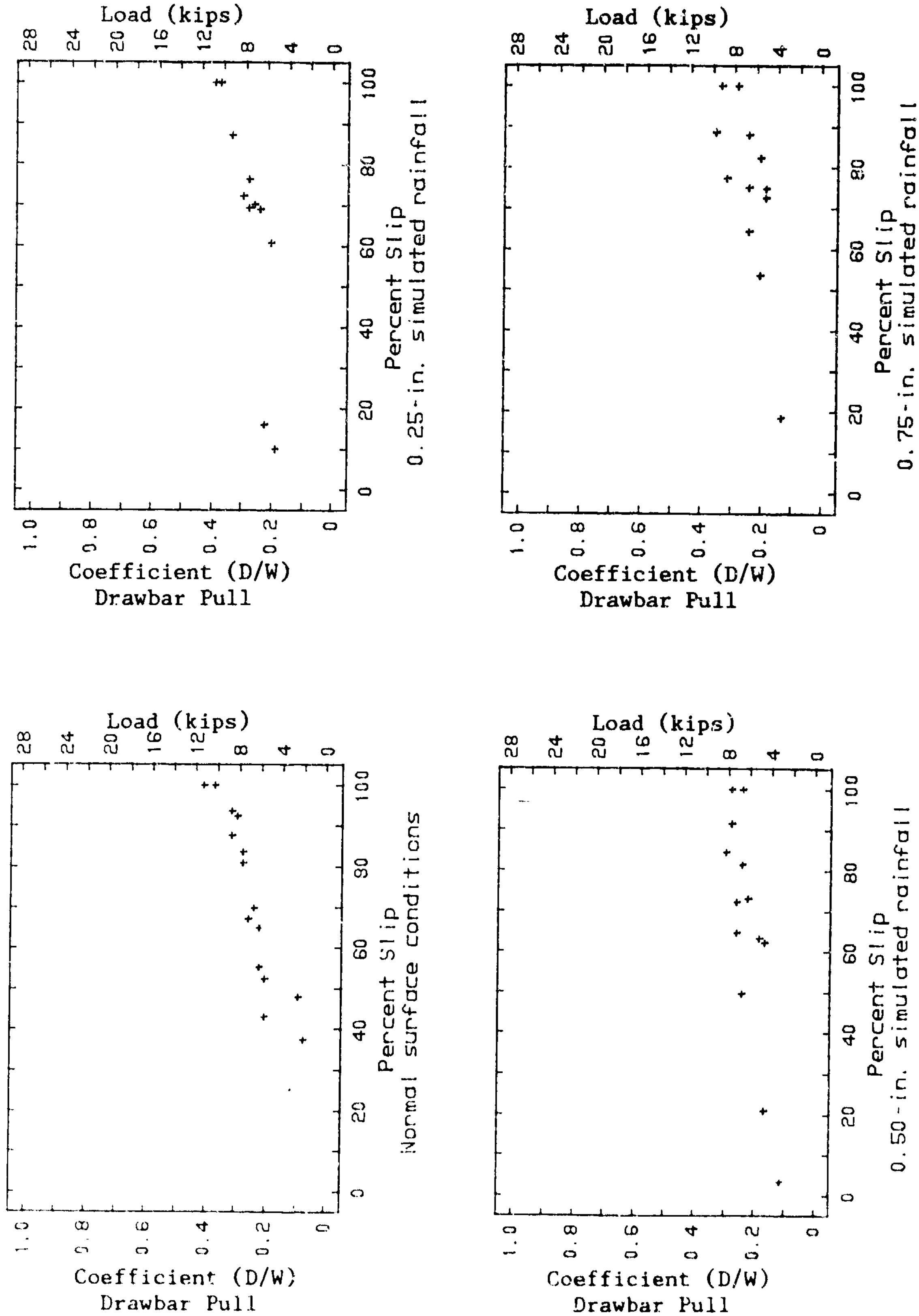


LAV25; Fort Chaffee, Ark., SC Soil

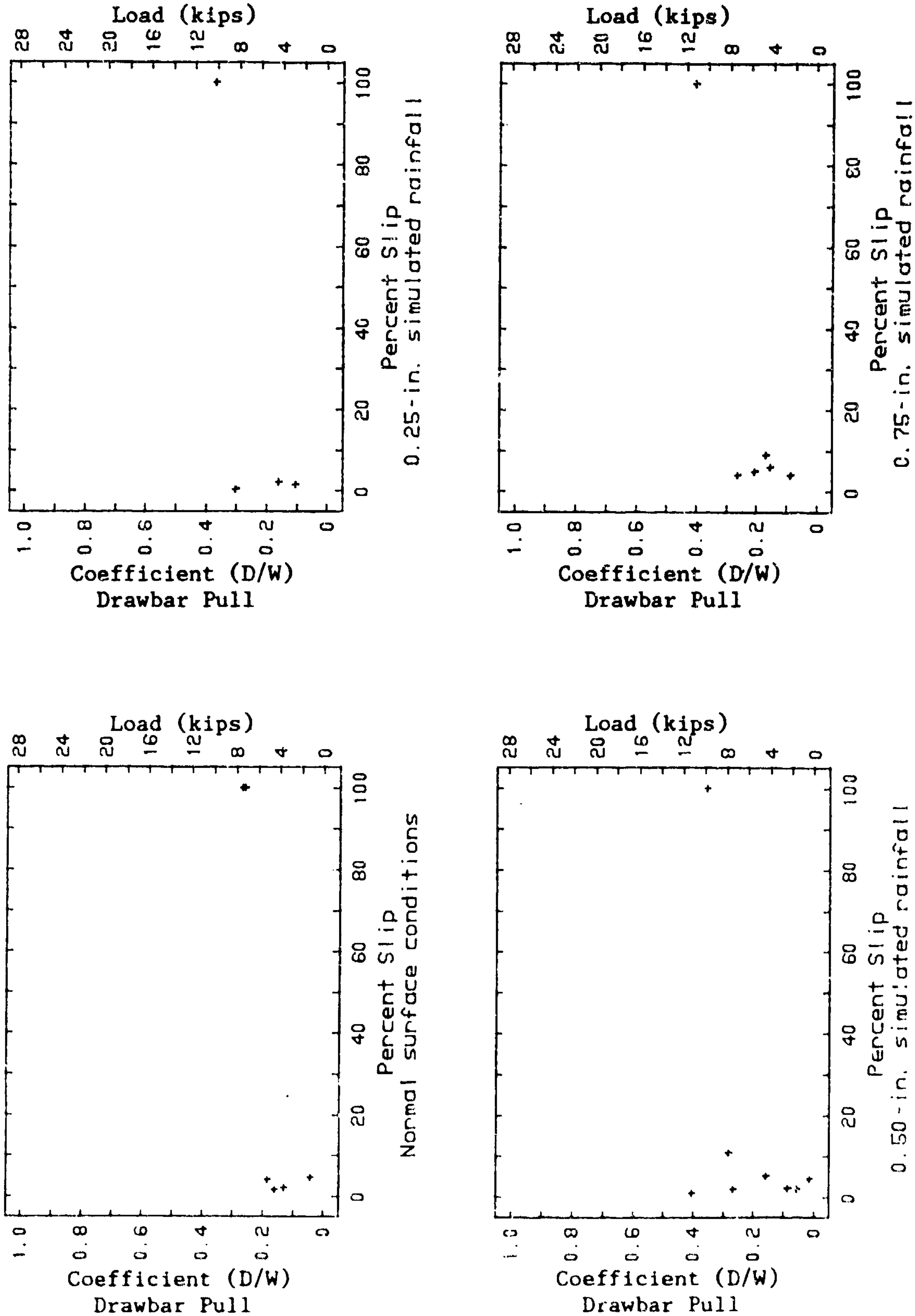




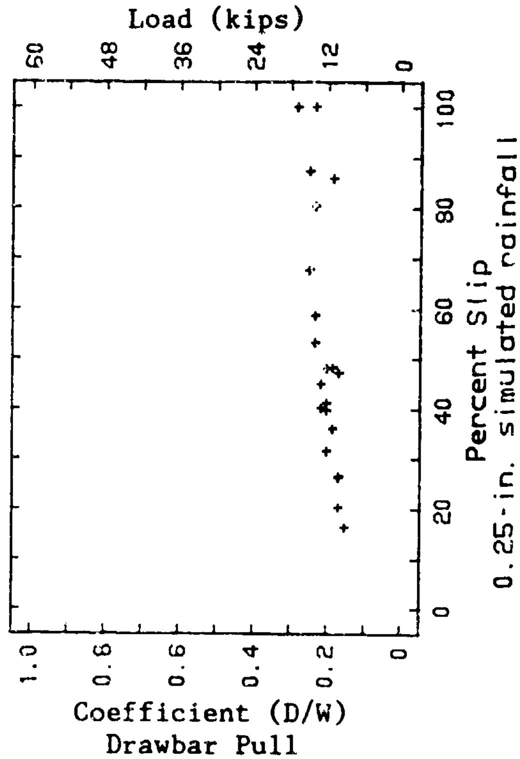
LAV25; Fort Chaffee, Ark., SC Soil

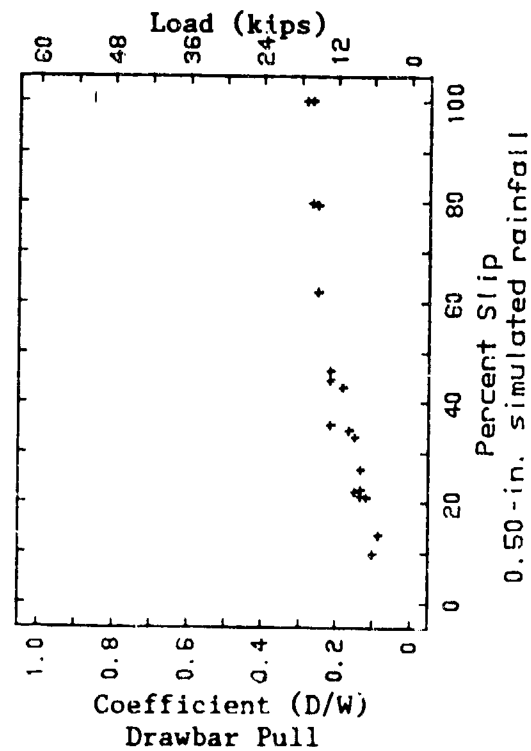


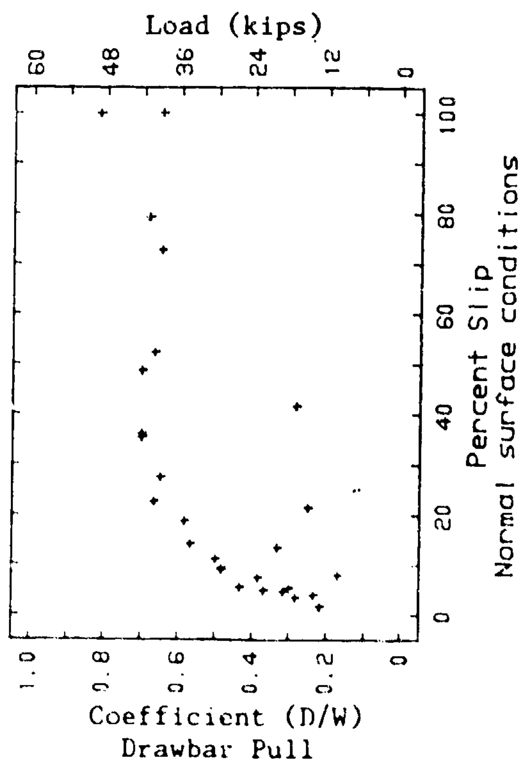
LAV25; Fort Chaffee, Ark.; SM Soil



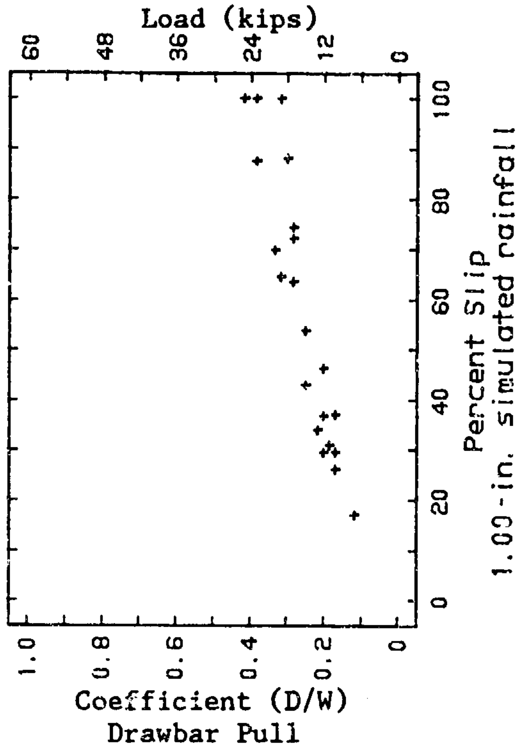
LAV25; Duckport, La.; SP Soil

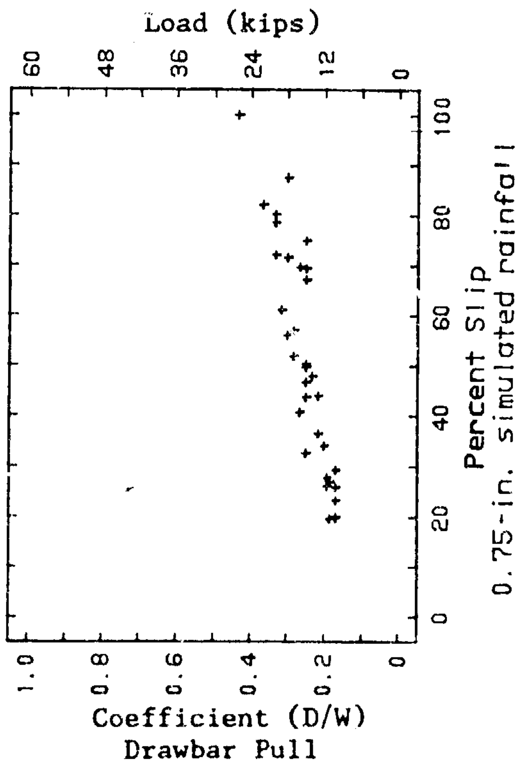




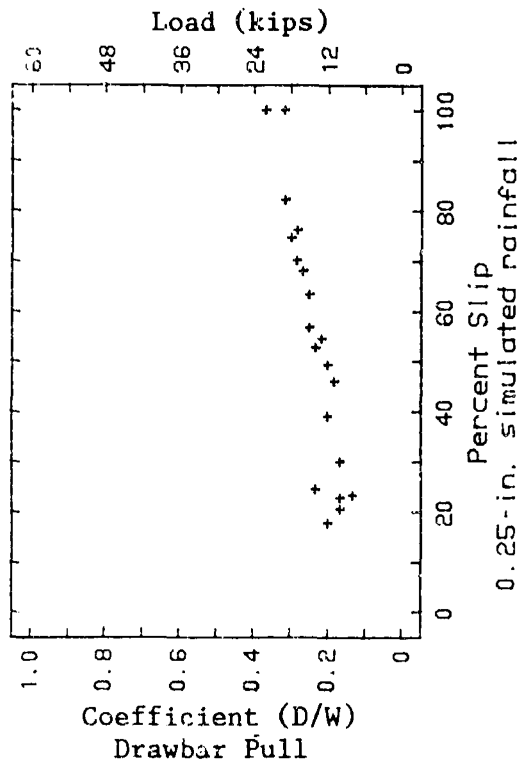


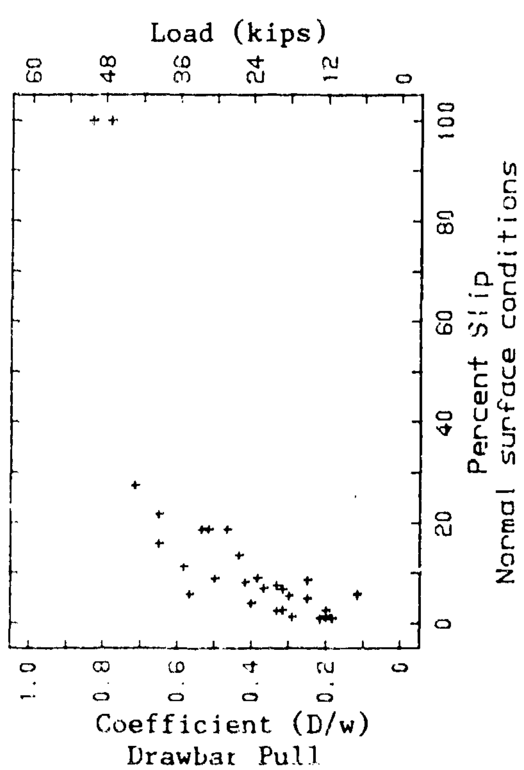
HEMTT: Duckport, La.; CH Soil

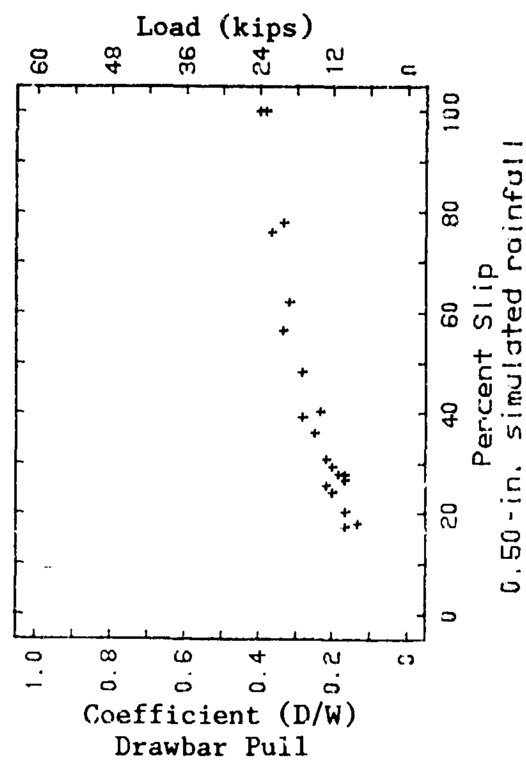




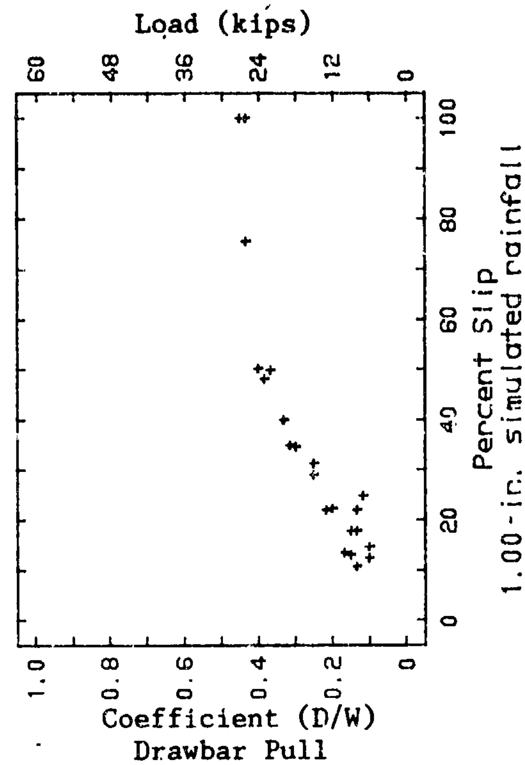
HEMTT; Duckport, La.; CH Soil

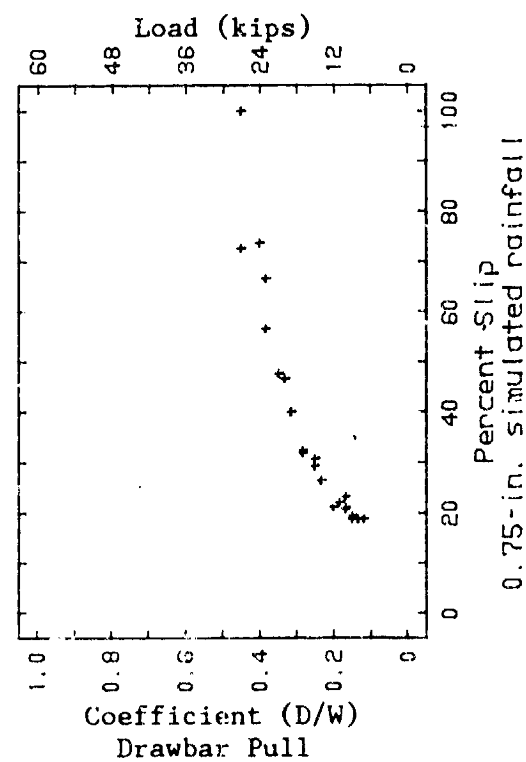




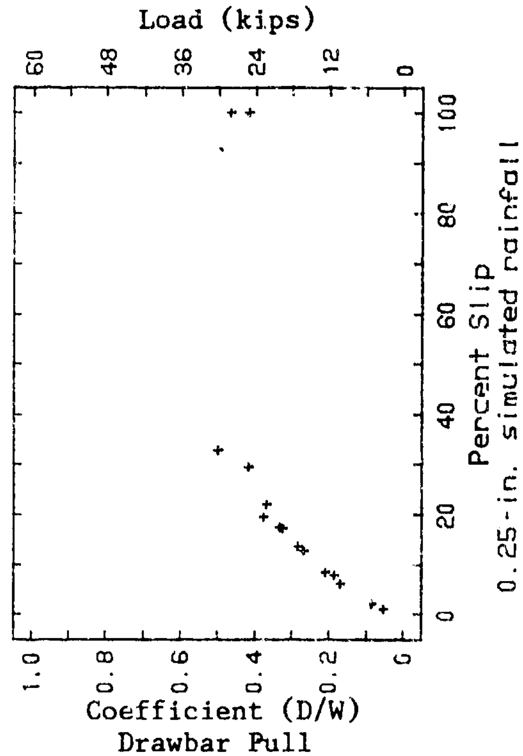


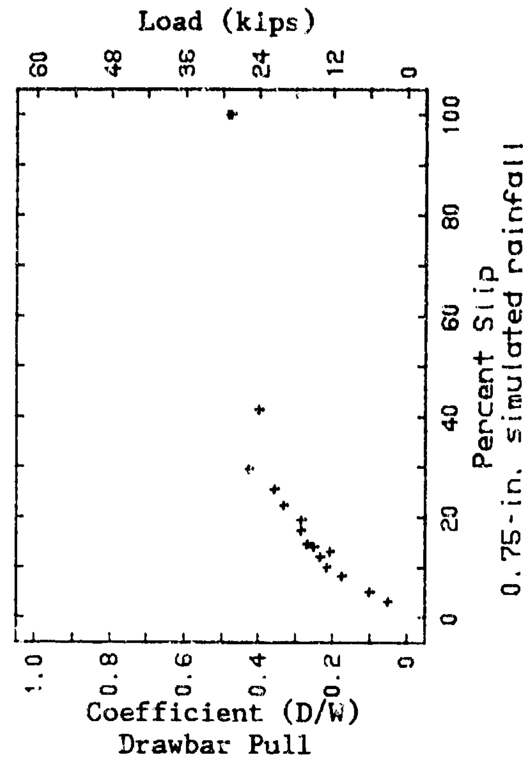
HEMTT: Duckport, La.; CL Soil

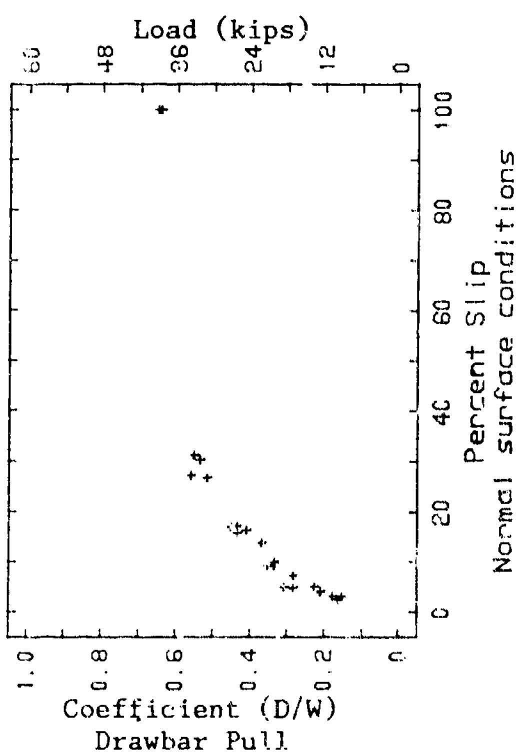


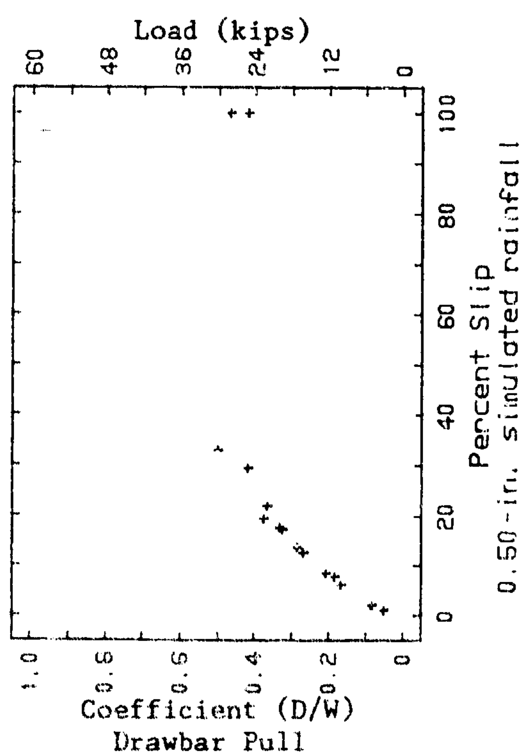


HEMTT; Duckport, La.; CL Soil

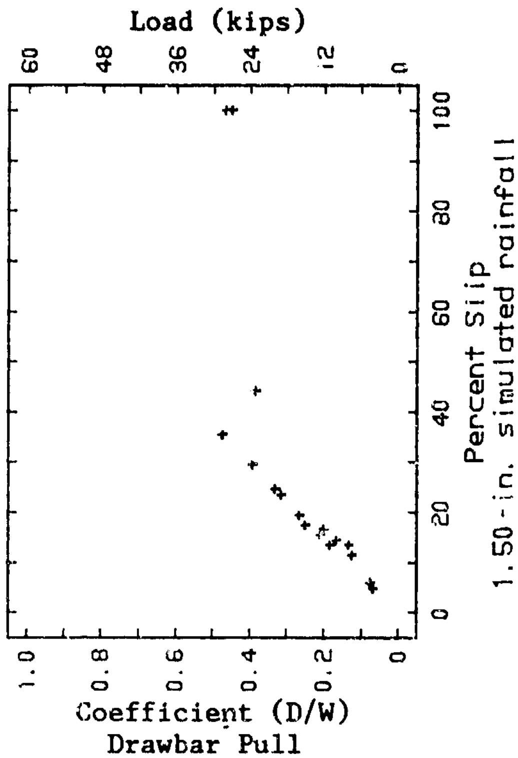


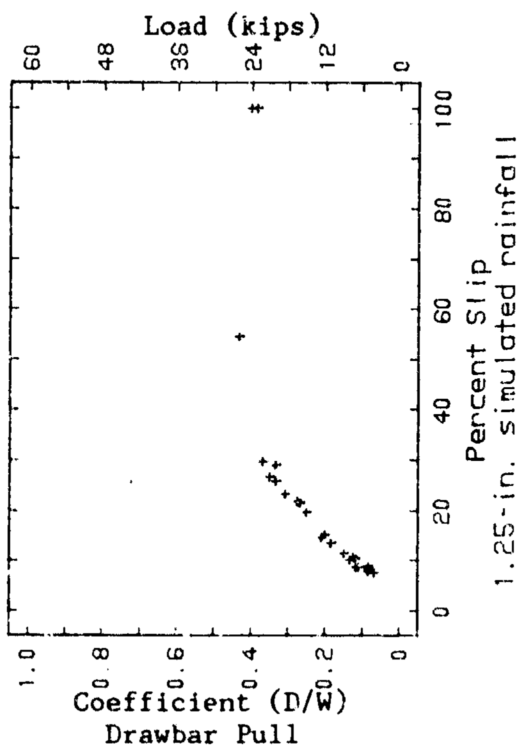






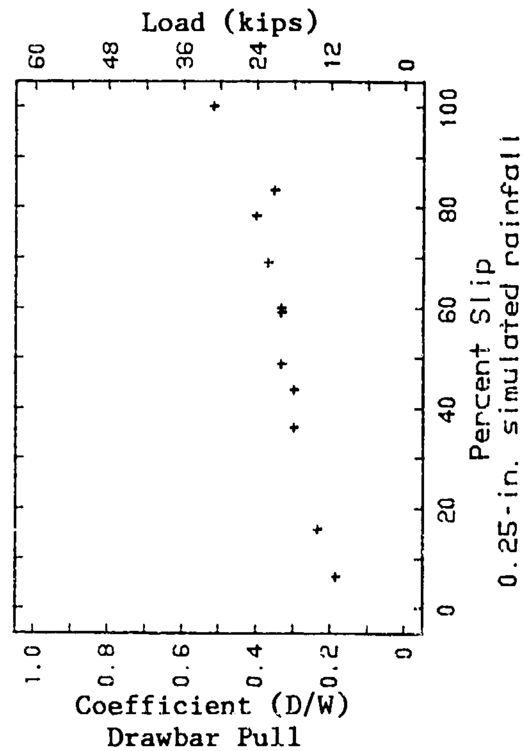
HEMTT; LeTourneau, Miss; ML Soil



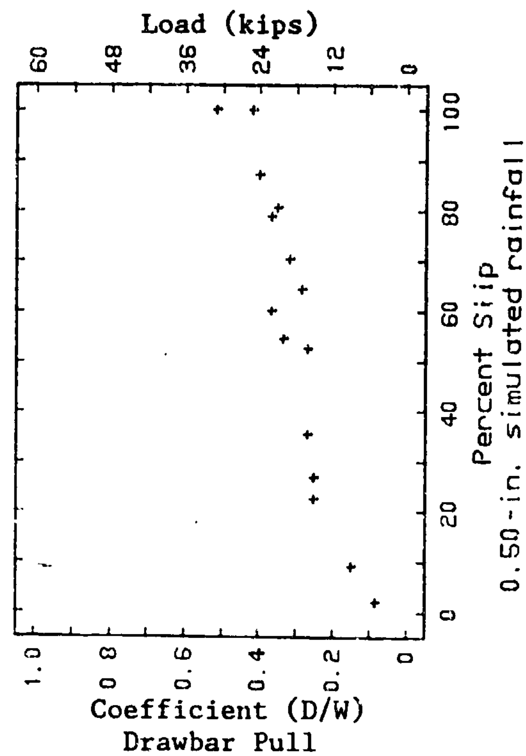


HEMTT; LeTourneau, Miss.; ML Soil

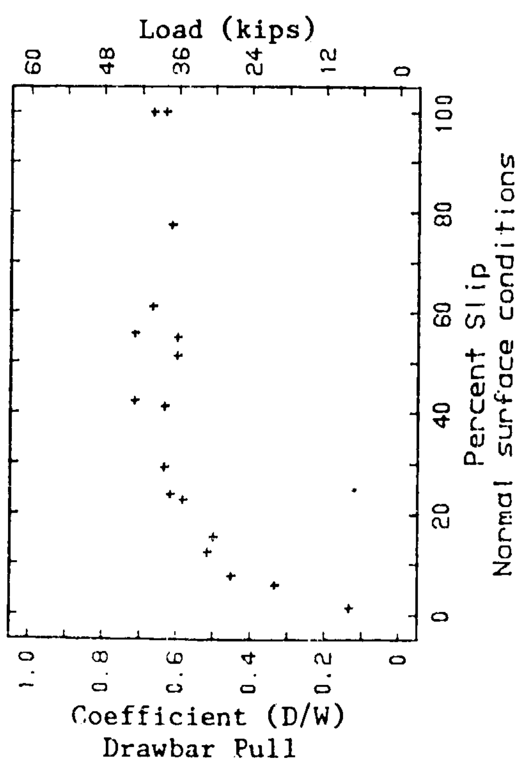
Plate 34



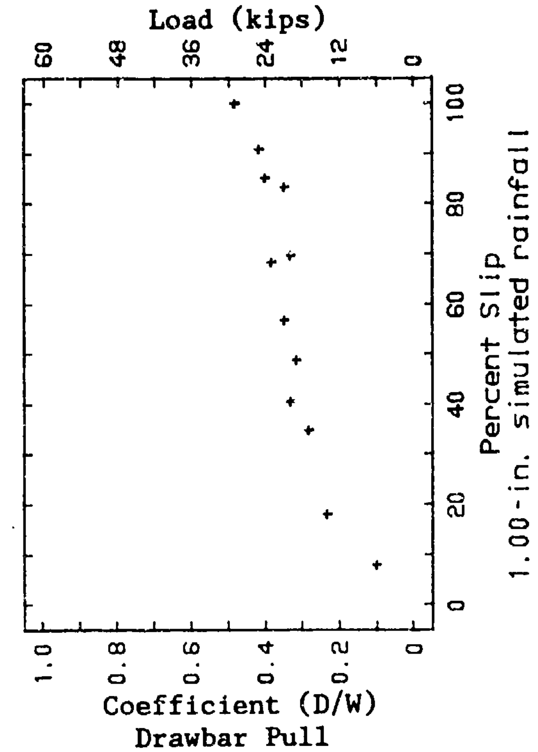
Load (kips)
60
48
36
24
12
0
100
80
60
40
20
0
Percent Slip
0.25-in. simulated rainfall
1.0
0.8
0.6
0.4
0.2
0
Coefficient (D/W)
Drawbar Pull

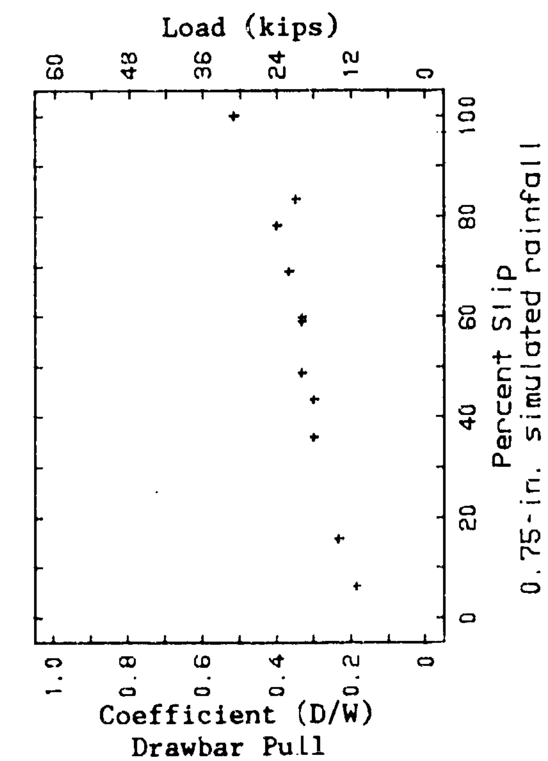


Load (kips)
60
48
36
24
12
0
100
80
60
40
20
0
Percent Slip
0.50-in. simulated rainfall
1.0
0.8
0.6
0.4
0.2
0
Coefficient (D/W)
Drawbar Pull

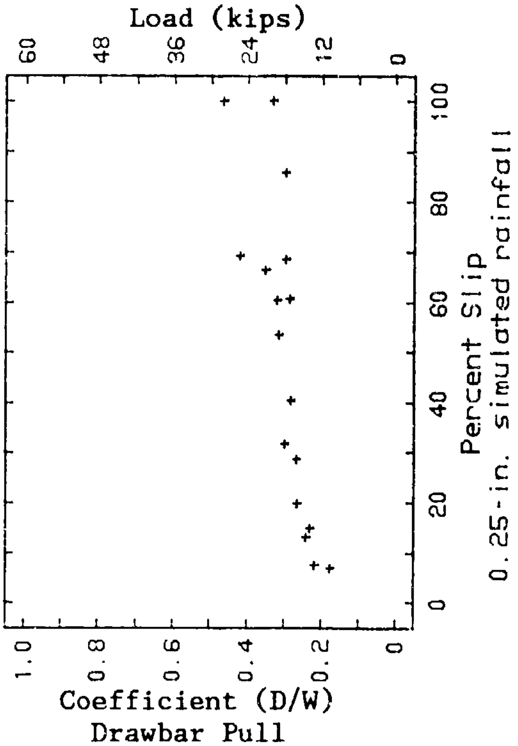


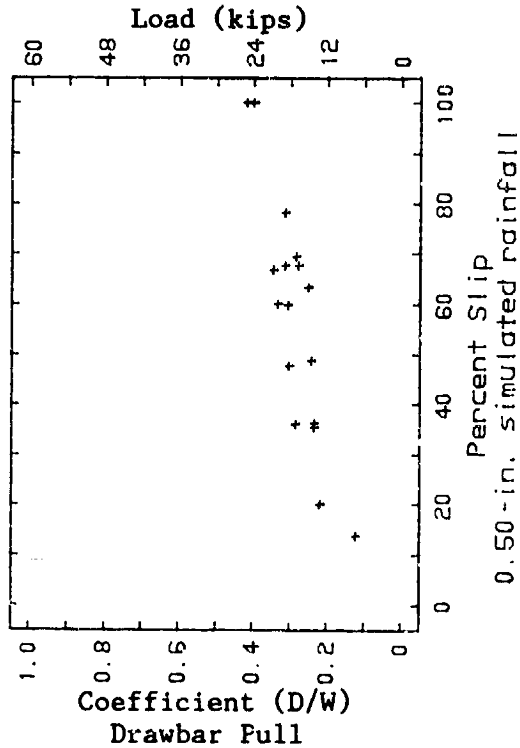
Load (kips)
60
48
36
24
12
0
100
80
60
40
20
0
Percent Slip
Normal surface conditions
1.0
0.8
0.6
0.4
0.2
0
Coefficient (D/W)
Drawbar Pull

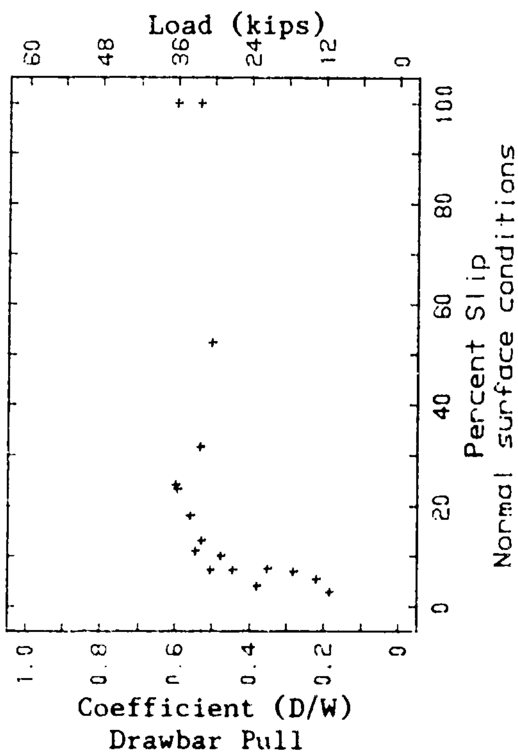




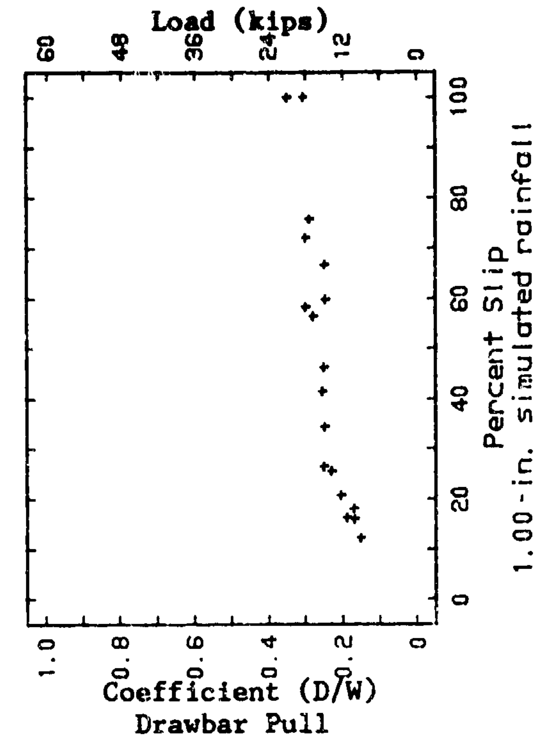
HEMTT; Fort Chaffee, Ark.; SC Soil

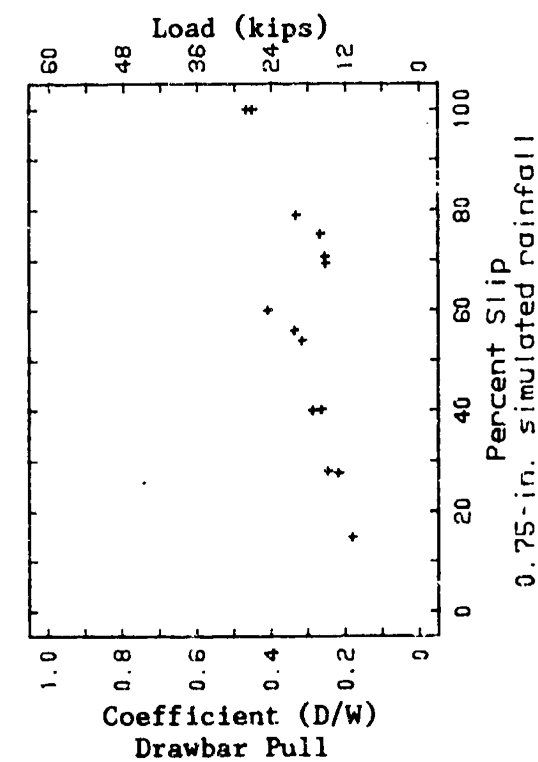




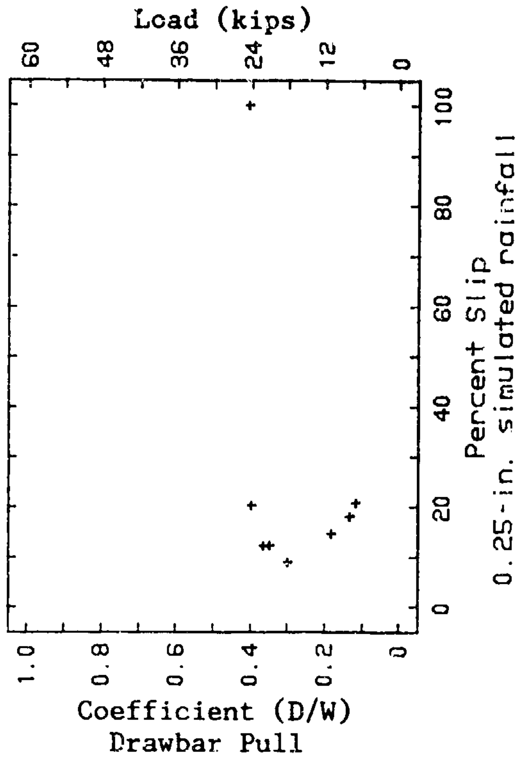


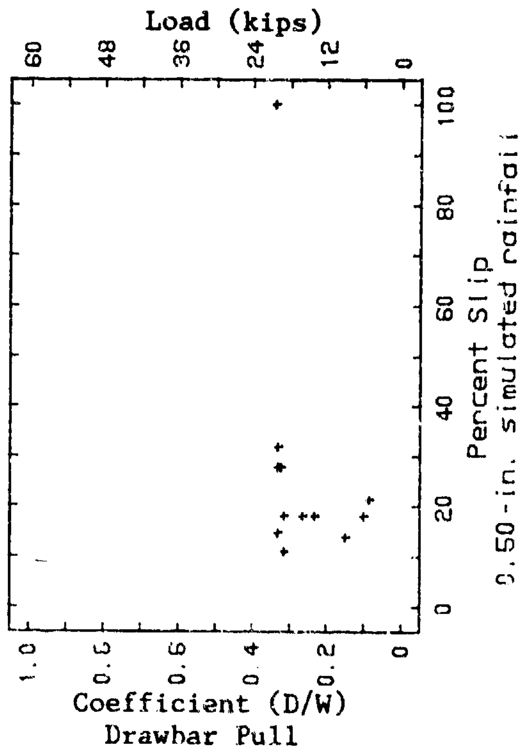
HEMTT; Fort Chaffee, Ark.; SM Soil

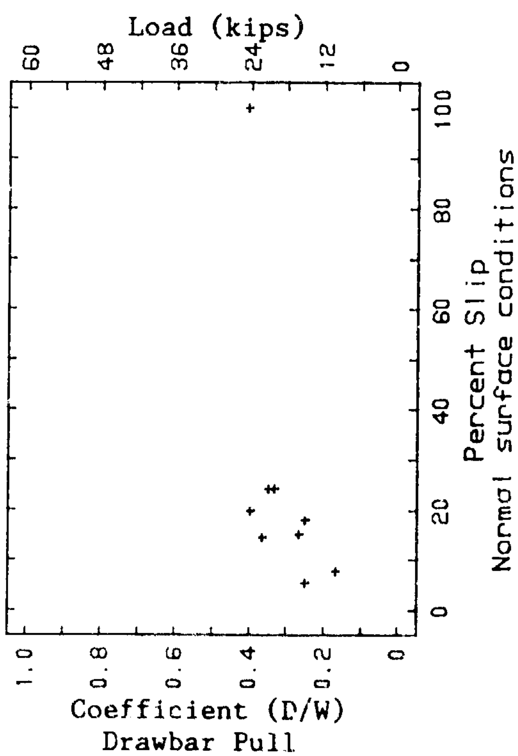




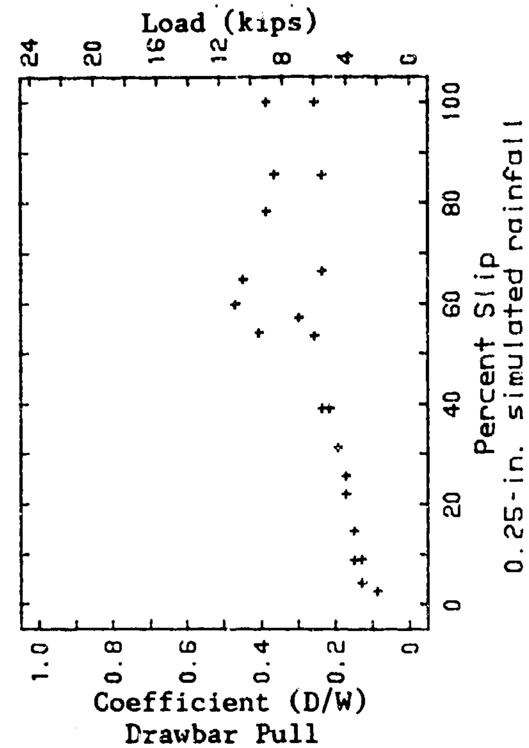
HEMTT; Fort Chaffee, Ark.; SM Soil

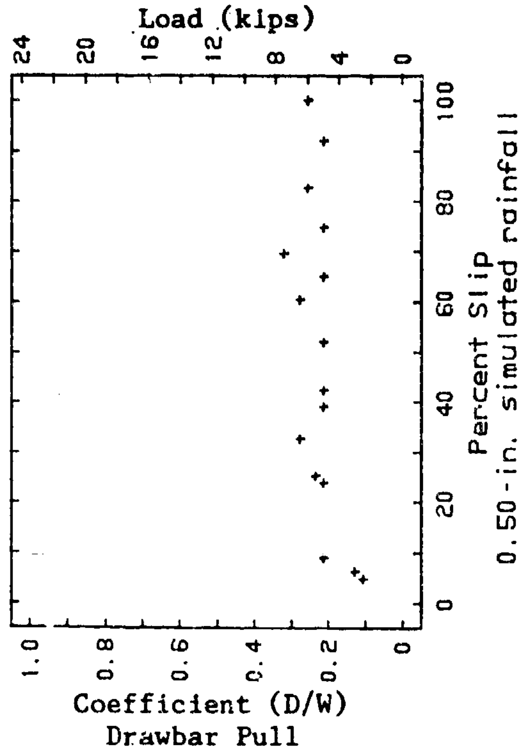


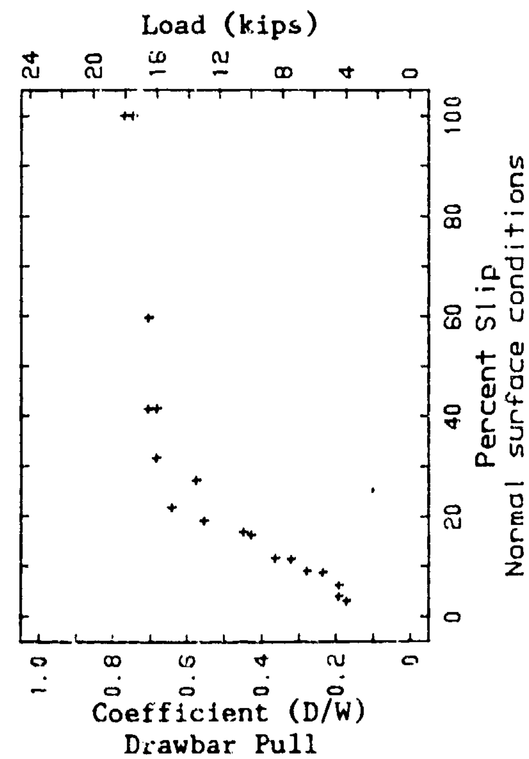




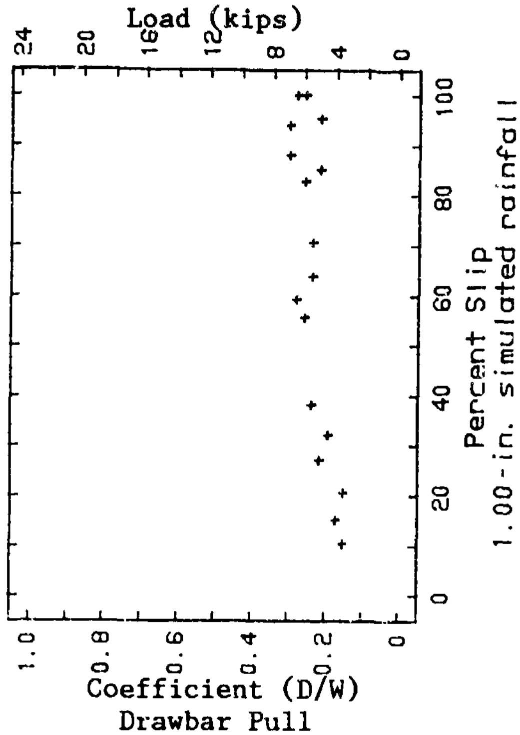
HEMTT; Duckport, La.; SP Soil

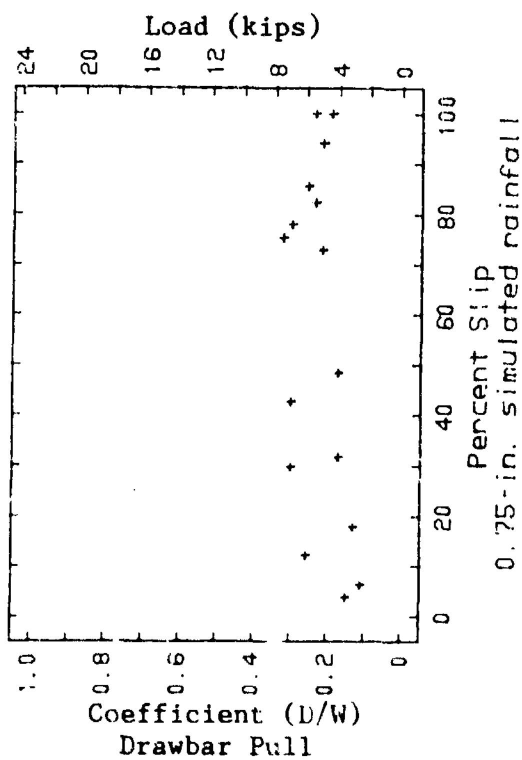




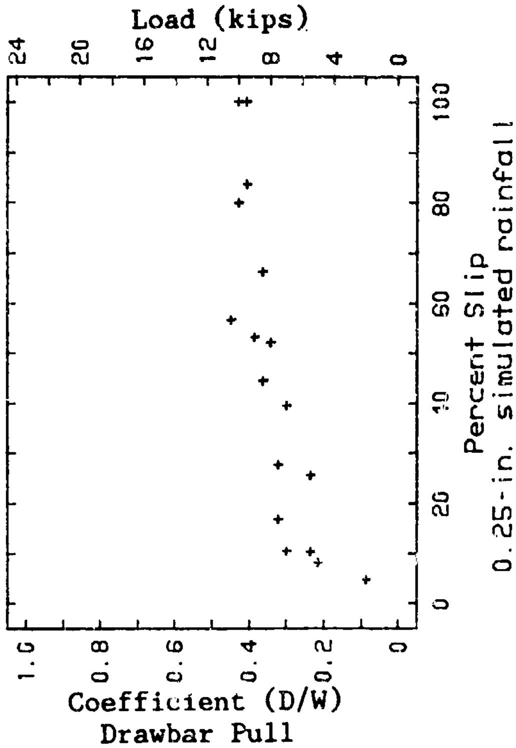


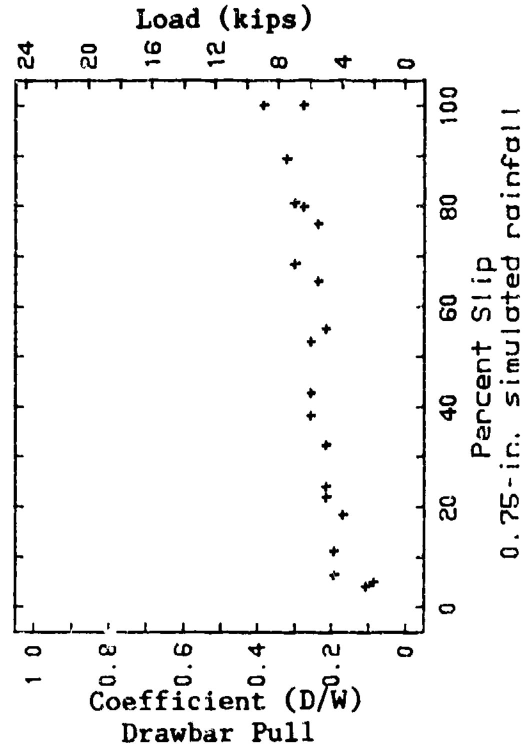
M113A1; Duckport, La.; CH Soil

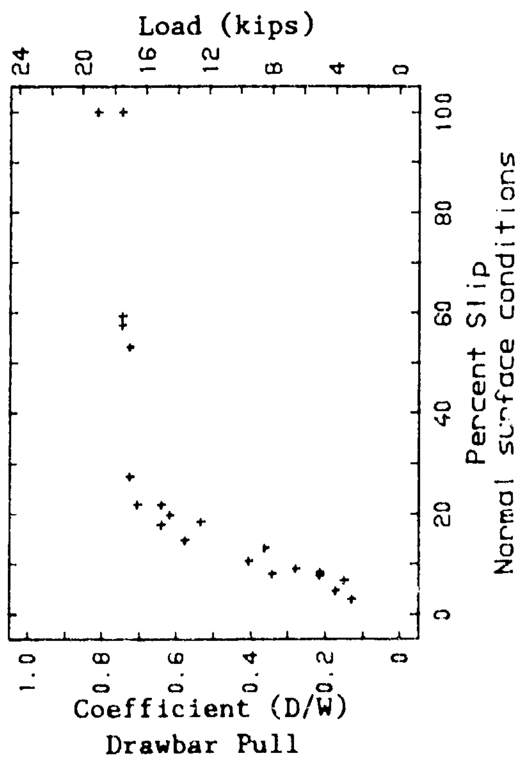


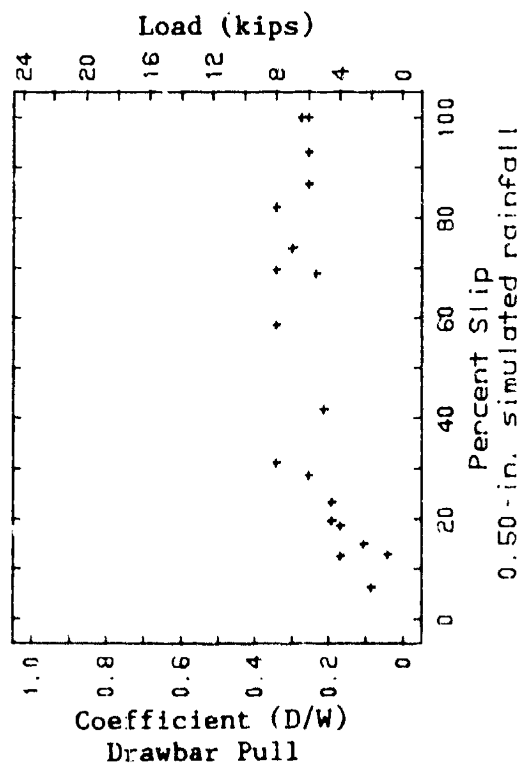


M113A1; Duckport, La.; CH Soil

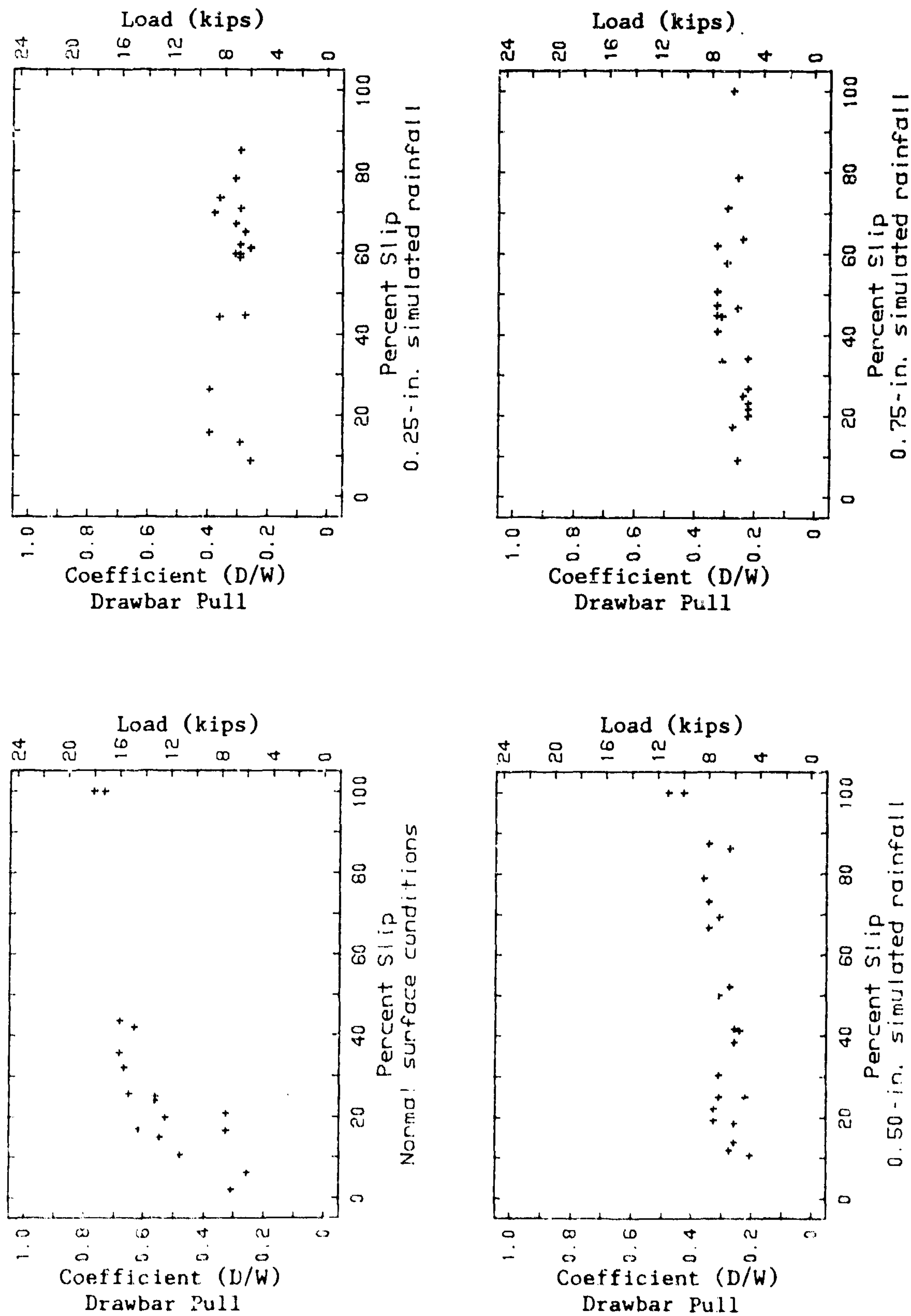




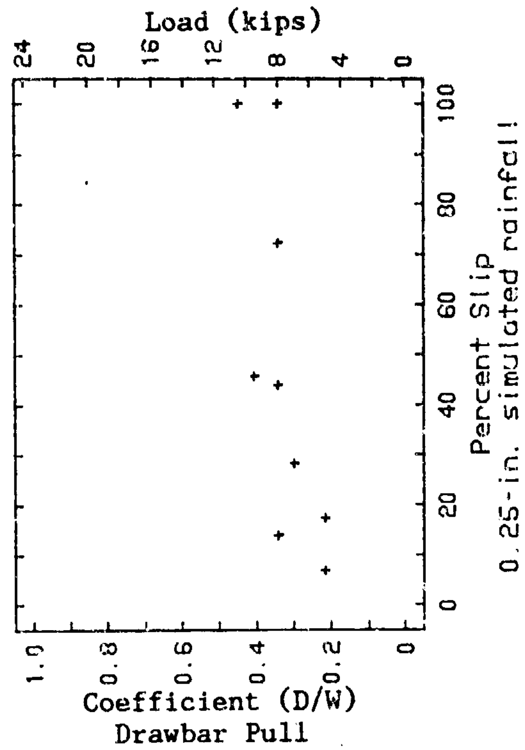


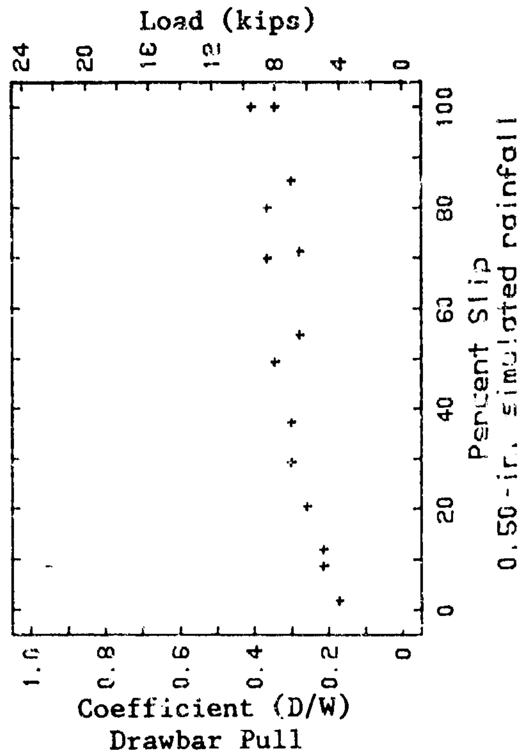


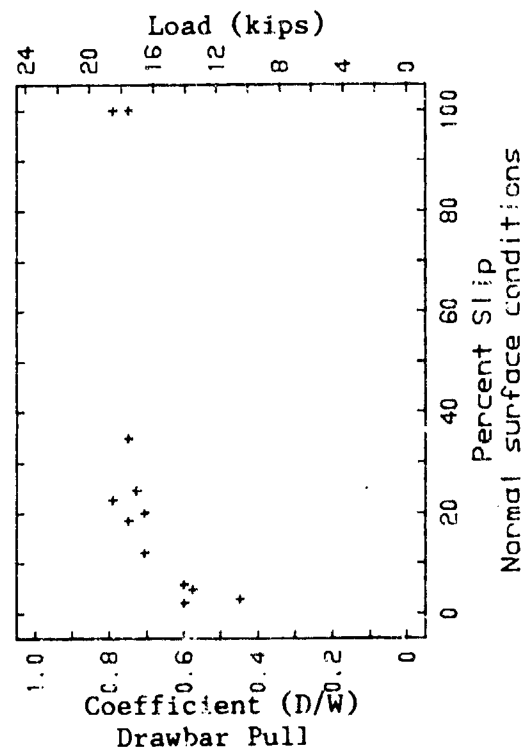
M113A1; Duckport, La.; CL Soil



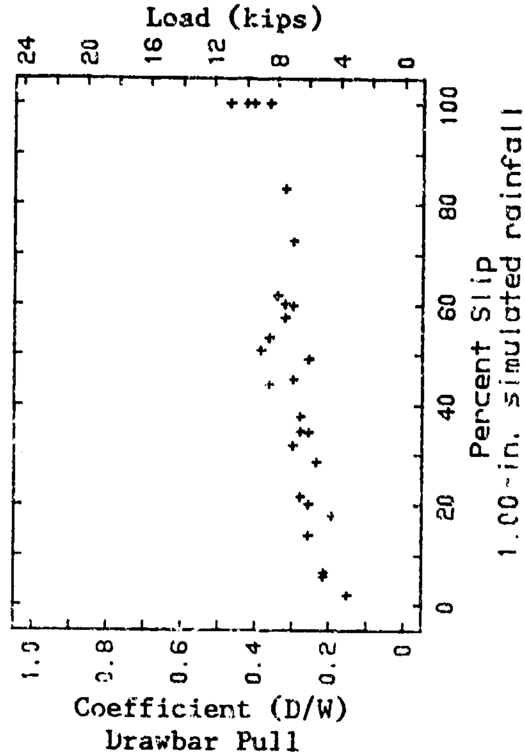
M113A1; LeTourneau, Miss.; ML Soil

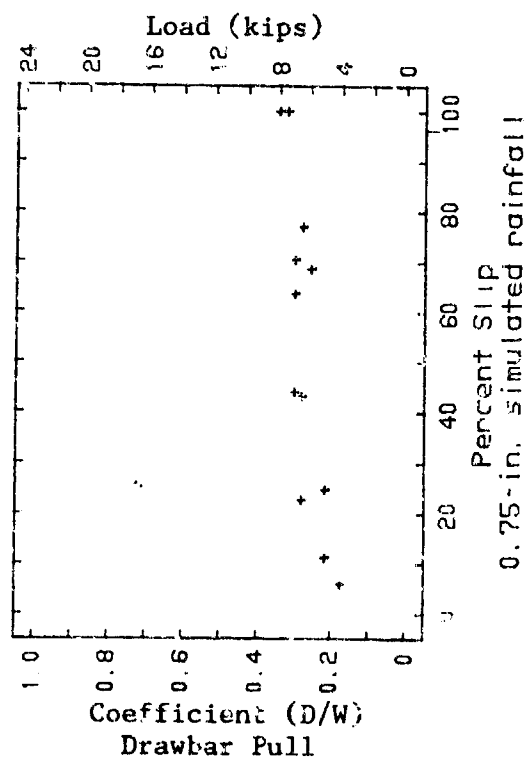




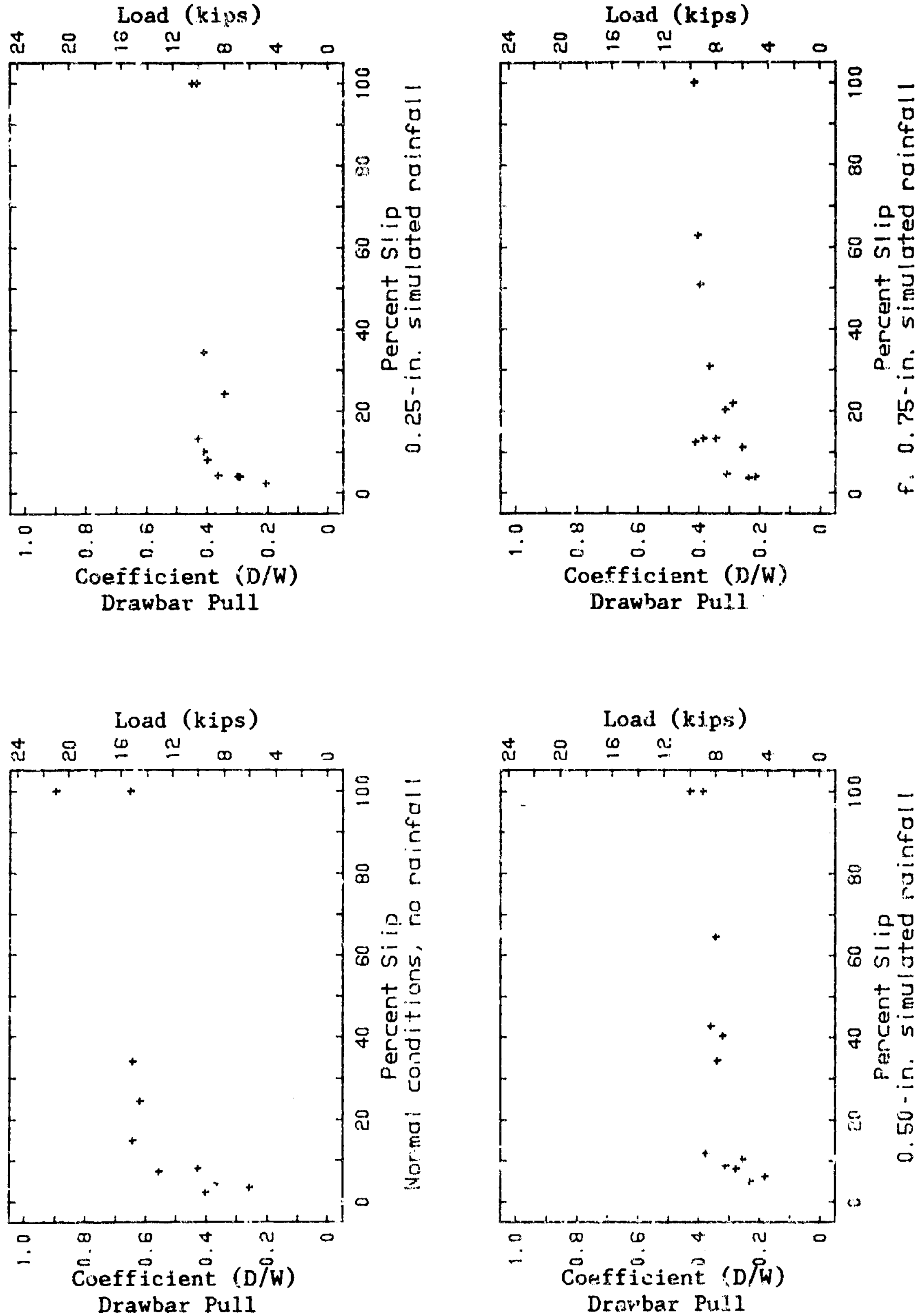


M113A1; Fort Chaffee, Ark.; SC Soil

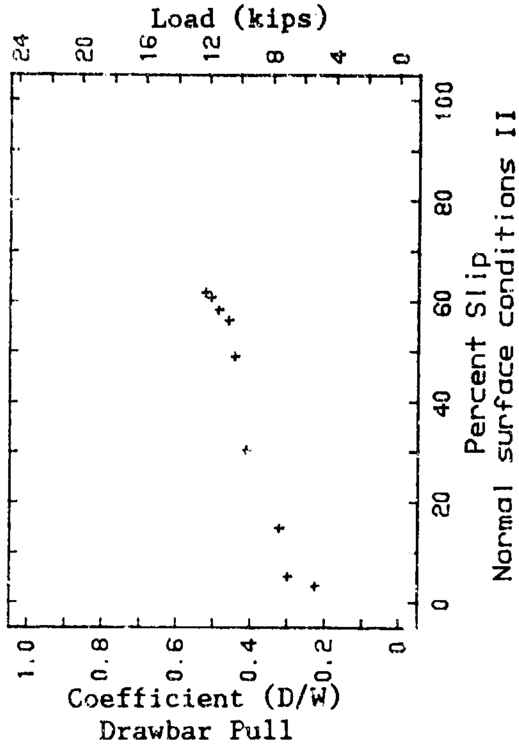


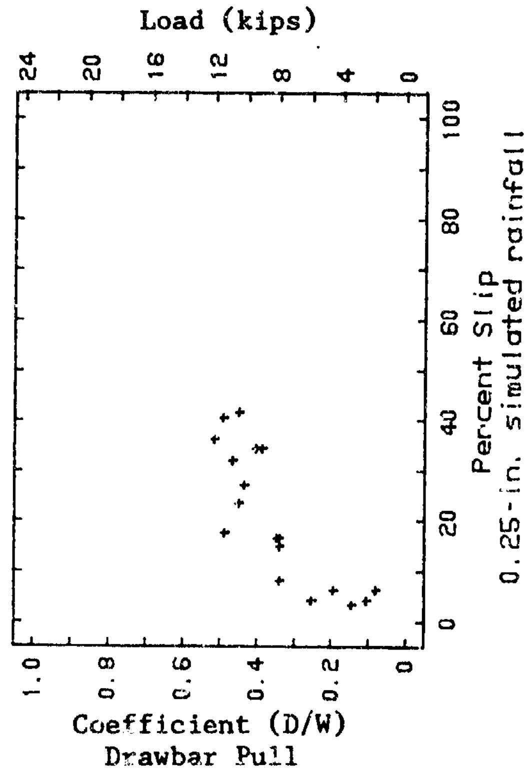


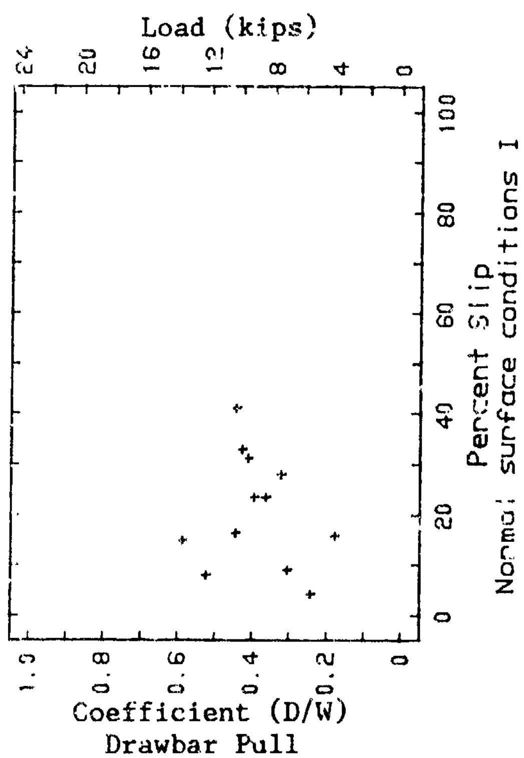
M113A1; Fort Chaffee, Ark.; SC Soil



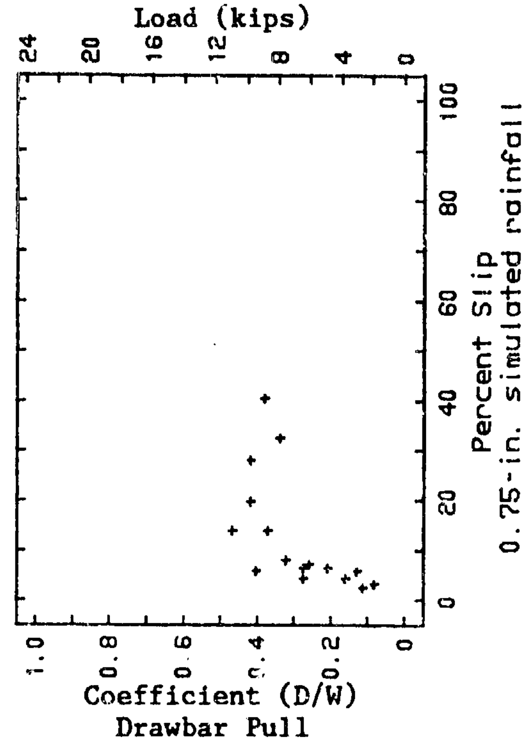
M113A1; Fort Chaffee, Ark.; SM Soil Plate 46

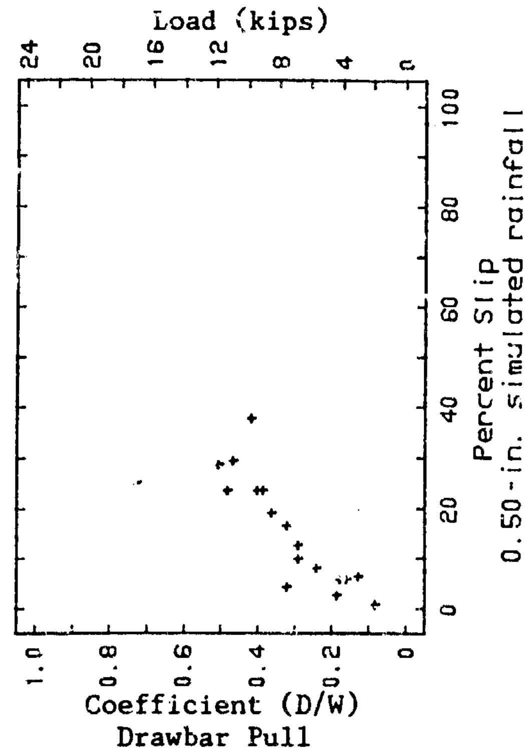






M113A1; Duckport, La.: SP Soil





M113A1; Duckport, La.; SP Soil

APPENDIX A: DEFINITION OF TERMS

The following are definitions of terrain and vehicle terms:

a. Coarse-grained soil. A soil of which more than 50 percent of the grains, by weight, will be retained on a No. 200 sieve (larger than 0.074 millimeters in diameter).

b. Cone index (CI). An index of the shearing resistance of a medium obtained with a cone penetrometer (Figure A1). The value obtained represents the vertical resistance of the medium to penetration at 6 feet/minute of a 30-degree cone of 0.5 $inches^2$ base or projected area. The value, although usually considered dimensionless in trafficability studies, actually denotes pounds of force on the handle divided by the area of the cone in square inches (i.e. pounds per square inch).

c. D/W_{20}. Drawbar pull in pounds at 20 percent wheel or track slip divided by vehicle weight in pounds.

d. Drawbar pull (net traction). The force available for external work in a direction parallel to the horizontal surface over which the vehicle is moving.

e. Drawbar pull coefficient (D/W). Drawbar pull in pounds divided by vehicle weight in pounds.

f. Fine-grained soil. A soil of which more than 50 percent of the grains, by weight, will pass a No. 200 US standard sieve (smaller than 0.074 millimeters in diameter).

g. Moisture content. The ratio, expressed as a percentage of the weight of water in the soil to the dry weight of the solid particles.

Figure A1. Cone Penetrometer

h. Off-road. Operation of a vehicle cross-country or operations on virgin terrain and not on a preestablished path.

i. On-road. Operation of a vehicle on primary roads, secondary roads, or trails.

j. Sand. A coarse-grained soil with the greater percentage of coarse fraction (larger than 0.074 millimeters) passing the No. 4 sieve (4.76 millimeters).

k. Slip. The percentage of track or wheel movement ineffective in advancing a vehicle forward.

l. Towed motion resistance. The force required to tow a given vehicle in neutral gear under given test conditions.

m. Traction. The total force output of the traction device acting parallel to the surface and in the direction of travel.

n. Unified Soil Classification System (USCS). A soil classification system based on identification of soils according to their textural and plastic qualities and on their grouping with respect to engineering behavior.